Ball Lightning and Bead Lightning

EXTREME FORMS OF ATMOSPHERIC ELECTRICITY

Ball Lightning and Bead Lightning

EXTREME FORMS OF ATMOSPHERIC ELECTRICITY

James Dale Barry

Springer Science+Business Media, LLC

Library of Congress Cataloging in Publication Data

Barry, James Dale.
Ball lightning and bead lightning.

Bibliography: p.
Includes index.
1. Ball lightning. 2. Beaded lightning. I. Title.
QC966.7.B37 551.5'634 79-19017

ISBN 978-1-4419-3200-6 ISBN 978-1-4757-1710-5 (eBook)
DOI 10.1007/978-1-4757-1710-5

© 1980 Springer Science+Business Media New York
Originally published by Plenum Press, New York in 1980.
Softcover reprint of the hardcover 1st edition 1980
A Division of Plenum Publishing Corporation
227 West 17th Street, New York, N.Y. 10011

All rights reserved

No part of this book may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, microfilming, recording, or otherwise, without written permission from the Publisher

Preface

The purpose of this monograph is to review the known physical aspects of two unusual forms of atmospheric luminous phenomena, to deduce their characteristics and properties, and to promote efforts to improve their understanding. These two forms, called ball lightning and bead lightning, have visual images that differ from the linear image associated with normal lightning. The terms "ball lightning" and "bead lightning" are used to denote atmospheric luminous forms which are occasionally observed and have the geometric shape suggested by their name. Yet, it is possible that neither phenomenon may in fact be a form of lightning in the sense of a continuous electrical discharge.

Bead lightning has been described as the residue of a cloud-to-cloud or cloud-to-ground lightning stroke and has the appearance of a series of luminous balls separated by dark regions, thus resembling a string of pearls, and remains visible for about one second. Ball lightning has been described as a single luminous globe appearing near the ground after a lightning stroke and also remaining visible for about one second. Both phenomena remain visible far longer than normal lightning flashes.

Based upon observational reports, both ball and bead lightning occur much less frequently than normal lightning. Although the occurrence of bead lightning may be as infrequent as that of ball lightning, its occurrence is an apparently accepted scientific fact. Ball lightning, on the other hand, has been the subject of much debate, and much skepticism has been expressed over its very existence. The existence of both phenomena is accepted by this author in view of the numerous reports and observations. No attempt is made to justify this assumption; rather, the attempt is made to present the evidence as it exists and to allow the reader the freedom of critical analysis and evaluation.

I gave this monograph its present title to convey the thought that atmospheric electricity may be involved in the formation of ball and bead lightning. I do not consider them to be discharges but rather

residues of discharges. I believe that the lightning discharge, including the air-to-air discharge of finite dimensions, is primarily responsible for the initiation of the phenomena. I believe that electrically excited atomic and molecular gas species are basically involved in the formation and persistence of the ball and bead lightning phenomena.

This monograph does not present a review of past reports and narrative discussions of visual sightings of ball or bead lightning events. That is not necessary here as many reports and reviews are readily available in the scientific literature. Likewise, a review of the many theories is intentionally not included. No single theory yet presented is self-consistent and satisfactorily explains the accumulated evidence. It is my current belief that the term "ball lightning" has been used to describe not one but several phenomena, all with similar appearance but resulting from distinctively different source processes and formation mechanisms.

It was my intent to emphasize the physical aspects as deduced from the available evidence. The available evidence is contained within the numerous (more than a thousand) observational reports and subsequent discussions. The characteristics of ball lightning, for example, have been separated into categories that indicate properties of its appearance, such as luminosity, motion, emissions, and decay, and its effect upon observers and the environment. Deduced properties, such as mass density, energy density, temperature, and electromagnetic field effects, have also been included.

I have included a discussion of the important experiments to produce ball-lightning-like phenomena under controlled conditions. The experiments have continued for over 100 years and various means to duplicate the natural formation mechanism have been used. Some attempts were designed to duplicate the natural discharge under the assumption that a lightning stroke induces the formation of bead and ball lightning. Some experimental methods attempted to create localized accumulation of relatively high ionization on the assumption that the end result would resemble the desired phenomena and could be achieved by laboratory methods. Other methods have been used that depended upon doping localized regions of air with foreign material, such as metal ions or hydrocarbon gases, on the assumption that such accumulations, though infrequent in nature, could reproduce a lightning-generated phenomenon.

A collection of photographs as evidence for both lightning forms has been assembled and included for critical evaluation by the reader. The events surrounding the photographs are discussed and the physical evidence reviewed. Not all the photographs are interpreted here as

truly being examples of the two lightning forms. It is a fact of the investigation that such photographic evidence cannot be conclusive, since various interpretations may be made. The reader may certainly reach a conclusion different from that of others. The author has not had the original photographic negatives available for evaluation nor discussed the photographs with each of the original photographers. Many of the original photographs and negatives are unavailable at this time because of the intervening period of years since the photographs were first published.

A large number of references to reports and discussions of the two lightning forms have been included. These references may be of use to those interested in the pursuit of first-person information. The reports included here were published in scientific journals and magazines and appeared during the last 300 years. The more than 1600 references included make this the most complete bibliography available on these lightning forms.

An attempt was made to keep the use of mathematical notation, equations of physics, and derived functions at a minimum. It was not possible to eliminate all equations and symbols as the content required their use for explanation and clarity. The symbols and notations are defined where used and cgs units are used, although English units are occasionally included for ease of comparison with an original report or fact.

It is the author's hope that this monograph will stimulate additional scientific investigation. Such investigation has been lacking in this field because of the frequent classification of such lightning forms as imaginary. Scientific investigations have also been hampered by the lack of definitive evidence. It is hoped that this monograph will help bridge the gap between popular publications and serious, but often unavailable, scientific discussions of these lightning events.

James Dale Barry
Los Angeles, California

Acknowledgments

The author has benefited greatly by the spirit of cooperation among numerous colleagues during the preparation of the manuscript. The long association and continued comments by Dr. Stan Singer, Director of Athenex Research Associates, Pasadena, California have proved invaluable and have greatly improved the quality of the manuscript. Dr. Singer is well known for his book, *The Nature of Ball Lightning,*

Plenum Press, New York, 1971. The author and Dr. Singer have exchanged information on ball lightning for almost 15 years.

I also appreciate the cooperation of Dr. P. Hubert of S.E.P., C.E.N., Saclay, France for various reports and prints, Dr. D. Tompkins of Terrene Corporation, Refugio, Texas for the use of his unpublished material and photographs, Dr. J. R. Powell of Brookhaven National Laboratory for the use of his photographs, Professor R. E. Orville of the State University of New York at Albany, New York for comments and the use of his photographs, Mr. D. W. Davies of the National Physical Laboratory, Middlesex, England for a continued interchange on ball lightning, Professor M. A. Uman of the University of Florida, Gainsville, Florida, for his comments on bead lightning, and Dr. A. J. Eriksson for the use of his videotape photographs.

The courtesy of all the various journals and individuals who gave permission for the photographs to be reproduced and used herein is gratefully acknowledged. The authors and journals are individually recognized in the captions for the respective figures contained within the various chapters. The manuscript could not have been prepared without the typing skill and tireless efforts of Ms. Marlene Schneider of Gardena, California and the patient proofreading of Mr. C. E. Whited of Long Beach, California. Many of the photographs were prepared by Dr. C. J. Kennedy of Huntington Beach, California, who also improved the manuscript by his suggestions.

I must, of course, acknowledge the patience and aid given by my wife, Karen, over the past five years during the preparation of the manuscript. I appreciate her encouragement and that of the rest of my family, Diane and David.

Contents

1. Introduction *1*
1.1. Lightning 1
1.2. Existence of Bead Lightning and Ball Lightning 3

2. Bead Lightning *11*
2.1. Description 11
2.2. Bead Lightning Photographs 12
2.3. Bead Lightning Origins 28

3. Ball Lightning *33*
3.1. General Characteristics 33
3.2. Observed Properties 35

4. Deduced Characteristics of Ball Lightning *45*
4.1. Mass Density 45
4.2. Energy Density 46
4.3. Energy Interpretations 64
4.4. Temperature 70
4.5. Radiation 73
4.6. Magnetic Field 75
4.7. Inferences 76

5. Ball Lightning Photographs *79*
5.1. Photographic Evidence 79
5.2. Classes of Photographs 80
5.2.1. Class 1: Pulsating Illumination 80
5.2.2. Class 2: Multiple Path 85
5.2.3. Class 3: Lightning Channel Decay 91
5.2.4. Class 4: Pyrotechnic Appearance 100
5.2.5. Class 5: Stationary Image 105
5.2.6. Class 6: Uninterrupted Singular Trace 110
5.2.7. Class 7: Natural Discharges 118
5.2.8. Class 8: Artificial Phenomena 122
5.3. Unavailable Photographs 130

6. Skepticism *133*
6.1. Inferences 133
6.2. Optical Illusions 136
6.3. Perceptual Effects 138
6.4. Summary and Erroneous Identifications 139

7. Laboratory Ball Lightning *147*
7.1. Introduction 147
7.2. Type 1: Use of Natural Lightning 149
7.3. Type 2: Gaseous Electric Discharge 157
7.4. Type 3: Metallic Vapor 176
7.5. Type 4: Electrodeless Discharges 180
7.6. Summary and Reflections 194

8. Bibliography *203*
8.1. Journals and Periodicals 203
8.2. Ball Lightning, Bead Lightning, and Related References 204

INDEX 293

1

Introduction

1.1. Lightning

Lightning is one of the major wonders of nature, and its existence has excited people for thousands of years. However, the scientific investigation of lightning began only some two centuries ago. It was not until 1752 that d'Alibard in France and Franklin in America officially opened the era of electricity and laid the foundations for our modern electronics-oriented society. A discussion of these early experiments may be found in the first-hand communications of Franklin (1752) and Watson (1752a,b). The study of lightning has advanced from observation and speculation to include theoretical and experimental investigations based upon electromagnetic and plasma physics. The physics of normal lightning is considered by many scientists to be well understood today. Numerous details, of course, remain open for investigation.

A number of books are readily available which discuss the characteristics, physics, and origin of atmospheric electricity. I refer the reader to the writings of Arago (1854), Battan (1964), Chalmers (1957, 1976), Flammarion (1874), Israel (1950, 1957, 1971), Schonland (1950), Viemeister (1961), Coroniti (1963), and Uman (1969). The subject is interesting and I suggest reading the older matter as well, as it gives one a feeling for the development of concepts and an appreciation of the advances that have been made.

Lighting was defined by Uman (1969) as a transient high-current electric discharge whose path length is generally measured in kilometers. The electric charge transferred by an average lightning stroke was determined by Meese and Evans (1962) to be from 140 to 250 coulombs. The total duration of a lightning stroke is of order 0.2 sec and the average current transferred may be a thousand amperes.

Lightning discharges occur in air when the electric field associated

with an accumulation of charge within a localized region becomes sufficiently large to cause ionization and breakdown of an air path. Lightning discharges can occur from clouds to the ground, between clouds, within clouds, from clouds to open air, and from air to air as well. A cloud-to-ground discharge is really composed of several intermittent discharges and is followed by a ground-to-cloud discharge.

The total lightning discharge event is normally termed the *flash,* which last for hundreds of milliseconds. Many component discharges, termed the *strokes,* often make up a flash, and individually last for tens of milliseconds. Multiple strokes are often separated by about 40–50 msec. The stroke, in turn, is initiated by smaller discharges—the *leader* discharges. The cloud-to-ground channel breakdown which precedes the return stroke is termed the *stepped leader.* The stepped leader propagates downward as a series of discharges of short length and separated by about 50 μsec at a velocity of order 1×10^5 m sec^{-1}. The stepped leader effectively provides a channel for the return stroke by increasing the local ionization along its path.

The return stroke occurs when the electric field near the ground is large enough to allow upward charge movement. The return stroke is essentially a wave front of significant ionizing capability which propagates the ground potential upward along the path defined by the stepped leader. The return stroke produces a channel of high ionization so that the region between the wave front and the ground is traversed by intense currents. The return stroke is primarily responsible for the lightning channel luminosity and propagates upward with a velocity of one-third to one-half the velocity of light.

The lightning channel will decay after the currents have ceased to flow and the ionization of the path returns to that of the air medium. Charge movement in the cloud, however, may lead to additional discharges along the established return-stroke path. These secondary discharge strokes along the primary channel are preceded by a discharge called a *dart-leader* discharge, which increases the channel ionization and establishes conditions for another high-current return stroke. The dart leader propagates at a velocity of about 2×10^6 m sec^{-1}, i.e., faster than the stepped leader as it has an established path of ionization to follow. The dart leader and the stepped leader differ also in appearance. The dart leader is not branched, as is the stepped leader, because it does not have to search for an ionization path. If the original channel currents have ceased to flow for about 100 msec or longer, a dart-stepped leader may occur since the remaining channel ionization is insufficient to provide a well-defined path. The physics of the discharge

ionization path has been investigated, for example, by Loeb and Kip (1939).

The lightning terms such as strokes, stepped leaders, dart leaders, and ionization channels will be used in subsequent chapters. It is thought by some investigators that some characteristic of the decaying channel with its reduced ionization can lead to the formation of various lightning phenomena, including bead and ball lightning. The formation is attributed to regions of residual ionization produced at a channel bend, or by air discharges along the decaying path similar to clear-air lightning discharges, or by infrequently triggered peculiarities of a lightning channel not well understood at this time.

This brief discussion of the lightning event does not do justice to the real complexity of the subject and the various physical properties involved. A detailed discussion may be found in the references noted earlier. The various aspects of the lightning discharge are also discussed as individual items in the scientific literature.

1.2. Existence of Bead Lightning and Ball Lightning

The term *ball lightning* has been applied to the singular, luminous, persistent, and relatively small globular mass occasionally observed in the atmosphere and associated with thunderstorms and natural lightning. The term *bead lightning* has been applied to the series of apparently connected, luminous, persistent, and relatively small globular masses which are occasionally observed in the atmosphere and are often described as the residue of a natural lightning discharge.

The investigation and theoretical description of the two forms of atmospheric electricity are still largely dependent upon observational reports and discussions. Ball lightning and bead lightning represent atmospheric luminous forms which occur infrequently in nature, and when they do, trained observers are not normally present. Moreover, on-site investigation is hampered by the inability to cause and generate atmospheric discharges of ball lightning and bead lightning at will.

The very existence of ball lightning has been questioned, and many scientists have been and are still skeptical. The skepticism surrounding ball lightning is apparently a result of its infrequent occurrence and its observation and report by generally untrained observers: The reports and descriptions of the phenomenon have varied so greatly from occasion to occasion that the scientist who looks for consistency is frequently infected by doubt and skepticism.

Bead lightning, oddly enough, does not evoke the emotion and disagreement that ball lightning does. The major difference between the ball lightning and bead lightning observations is the personal involvement of the observer. Bead lightning is most often observed at a relatively large distance from the observer and is associated with normal cloud-to-ground and cloud-to-cloud lightning activity. By contrast, ball lightning is most often observed nearby and may not appear to be related in any normal fashion to a direct lightning stroke. The ball lightning event may be described as the unexpected observation of one of one of the rare forms of atmospheric electrical phenomena leading to extreme emotional responses from the observer. It is expected, therefore, that a ball lightning observation would hinder cool, objective reporting of the observation.

The emotional and personal response associated with the appearance of ball lightning is depicted in Figures 1.1 and 1.2. Figure 1.2 was reprinted from a famous book on atmospheric characteristics and properties by Flammarion (1874), and Figure 1.1 is from a related article (Flammarion, 1899). The presence of ball lightning was not ignored but taken rather seriously by nearby observers. The first-person reports often reflect the intimacy of the observation.

Photographic evidence for bead and ball lightning is more uncommon than reports on the two phenomena themselves. This may account for the apparently conflicting descriptions of some reports accompanied by photographs. It would appear that most photographs are highly questionable. Many photographs have been discussed at length in the journals, mainly with negative conclusions. All of the presently available photographs repooted to be of ball lightning are included in Chapter 5, and those identified as bead lightning are included in Chapter 2. Most of these identifications have been determined to be erroneous; only a few photographs may be considered as truly showing ball or bead lightning. Based upon this evidence, we must conclude that both ball lightning and bead lightning are extremely rare events. As will be discussed later, Tompkins, Rodney, and Gooding (1975), for example, have evidence suggesting that the probability of ball lightning and bead lightning occurring in the Midwest USA is about 1 per recorded 10^4 lightning events.

A large number of ball lightning and bead lightning reports have been evaluated, and the bibliography has been included in Chapter 8. These reports may be found, in most cases, in the readily available scientific journals and periodicals that have been published over the past 300 or so years. It is quite evident that even though ball lightning and bead lightning may be rare, each has received a considerable

Figure 1.1. Drawing illustrating the direct emotional involvement of a person confronted with a ball lightning appearance. Reprinted from C. Flammarion, "Les Victimes de la Foudre et ses Caprices," *Bull. Soc. Astron. Fr.*, **13,** 1899, p. 145.

Figure 1.2. Drawing illustrating the direct emotional involvement of a person confronted with a ball lightning appearance. Reprinted with permission of Harper and Brothers. Originally published by C. Flammarion, *The Atmosphere,* Harper and Brothers, 1874, and reprinted in R. A. Leonov, *The Riddle of Ball Lightning,* U.S. Dept. Commerce, JPRS: 36823, TT: 66-33253, 3 Aug. 1966.

amount of attention. Ball lightning is considered to occur more infrequently than bead lightning, yet the frequency of reports would suggest the opposite. This is to be expected, however, when one considers that bead lightning has been a scientifically accepted form while ball lightning has not been taken as seriously.

An analysis of the frequency of occurrence of ball lightning reports was made by Barry (1979), which produced an interesting distribution. The frequency distribution of the publication dates of about 1600 referenced ball lightning observations and discussions is shown in Figure 1.3. The data have been divided into three categories: (a) those describing the observation of a ball lightning event—about 500 occurrences; (b) the observation reports and those additional discussions of theories and characteristics—about 600 more; and (c) the observation and discussion reports, and those additional unverified reports—about

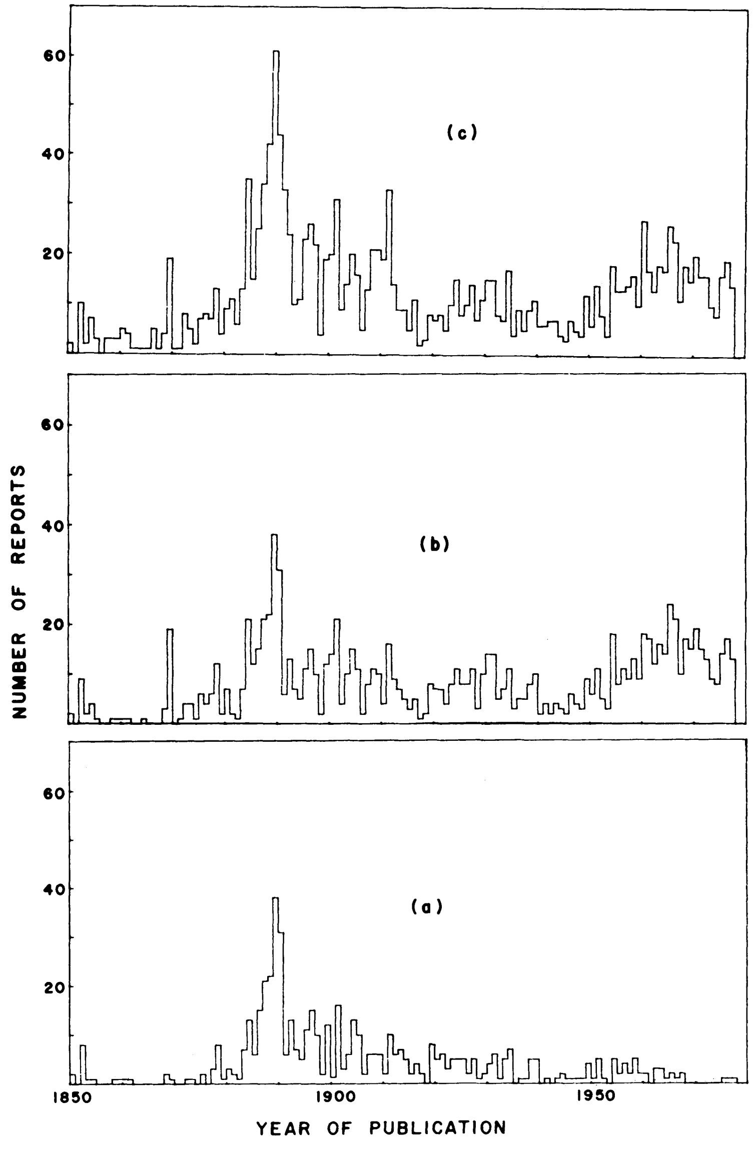

Figure 1.3. Frequency distribution by publication date of about 1600 ball lightning reports and discussions from scientific periodicals during the period from 1850 to 1978. The references are included in the Bibliography. Distribution (a) is based on about 500 observation reports, (b) is based on the observation reports in (a) and about 600 additional general discussion reports, and (c) is based on the reports in (a) and (b) and about 500 additional unverified reports. The limited data (54 events) from 1651 to 1849 are not shown. A 10-year cyclic distribution is not apparent.

500 more. The data from 1651 to 1849 are not shown, as only 54 events were found for that period.

It is now recognized that many reports of ball lightning were, in fact, due to the observation of other meteorological phenomena or to physiological misinterpretations. Examples include corona discharges, the St. Elmo's Fire phenomenon supported by localized high electric fields, bead lightning, and retina retention of a nearby lightning flash. The misidentification was often reinterpreted in letters subsequent to the original report and correctly identified. A detailed screening process to remove other possible erroneous, conflicting, or duplicative descriptions in different journals has not been applied by this author so as to avoid evaluator bias.

In an evaluation of ball lightning events in Holland, Arabadji (1976) reported that the events occurred with a 10-year cyclic period. He suggested that the occurrences were related to the almost 10-year cyclic behavior in solar activity. A cyclic distribution with a period of about 10 years is not apparent in the data shown in Figure 1.3. It is thought that the main peak near the year 1889 may reflect the intense interest in electrical events during that period when observational investigation of atmospheric electrical phenomena was popular. The distribution of Figure 1.3 when taken on a decade basis is similar to that accumulated by Paneth (1956) for the period 1800–1920. No other significance has been attributed to the distribution owing to various uncertainties in the available data.

It should be recognized that the frequency distribution of published reports as shown here may not correctly reflect the actual occurrence frequency of ball lightning in nature. The report frequency and geographic source distribution may be skewed as a result of publication bias, possible periodic public interest, misinterpretation and misidentification of the actual event, hesitancy of reporting by the observer, and lack of an available reporting vehicle. The frequency of ball lightning occurrence has been estimated by Tompkins, Rodney, and Gooding (1975) as about $3 \times 10^{-9}\ \text{km}^{-2}\ \text{min}^{-1}$ as derived from remote automatic lightning photographs. This value is equivalent to that deduced by Arabadji (1976). Brand (1923) and Norinder (1939) investigated reports in different areas and different periods and found that the number of ball lightning reports was about 3% of the number of reports of ordinary lightning strikes to ground in Northern Germany and Sweden. It must be recognized that such occurrence rates are dependent upon various skewing factors and may not be very accurate.

It is interesting to note that as many reports have been written about bead lightning and ball lightning discussing their properties,

defining theoretical models, or suggesting experimental similarities as have been written reporting first-hand observations. Clearly, the phenomena have stimulated people's imaginations for generations.

A major difficulty in the evaluation of ball lightning reports is that conflicting and widely varying properties for the phenomenon have been reportedly reported. Differences in color, size, motion, energy density, and decay mode have been noted by a number of researchers from surveys and analyses of reports. These include those by Arago (1854), Barry (1967a), Brand (1923), Dewan (1964), De Jans (1910), Jeffreys (1921), McNally (1966), Rayle (1966), Sauter (1895), and Singer (1971).

It is likely that several atmospheric electrical phenomena exist with similar but somewhat different characteristics. This postulate is supported by several experimental results. Laboratory ball lightning investigations have been conducted by a number of researchers, including recent experiments by Barry (1968a,c) with low-density hydrocarbon combustion, by Powell and Finkelstein (1969) with the excitation of molecular metastable energy levels using radiofrequency discharge techniques, and by Silberg (1965) with the large direct current production of metal vapors. All of the experimenters have produced persistent and luminous globes in the air at atmospheric pressure. Hubert (1975) also produced such phenomena with triggered cloud-to-ground lightning discharges. Each of these phenomena is distinctively different, yet all would be classified as ball lightning if observed in nature.

Ball lightning, as well as bead lightning, may be singular or multiple phenomena, and are obviously rare natural events, not well understood, and the source of infrequent investigation. I will continue to maintain my files on published reports and welcome contacts to enlarge its scope. Further experiments are planned. It is hoped that further research beyond observational evaluation will become attractive to many more scientists.

Specific descriptions of the bead lightning phenomenon including first-person observer reports and comments by various researchers may be found in the list in Table 2.1. These references are noted separately from the total reference list in Chapter 8 to provide easy reference to the bead lightning reports. Interested researchers may obtain a detailed concept of the phenomenon and of the various observations from the listed references.

2

Bead Lightning

2.1. Description

Bead lightning is also known by the terms pearl lightning, chain lightning, *perlschnurblitz,* and *éclair en chapelet,* to name a few. The bead lightning form is fairly well documented and discussed in the scientific literature. Although the number of reports and discussions of bead lightning is decidely less than of those involving ball lightning, bead lightning is an accepted form of atmospheric lightning. Goodlet (1937), for example, an atmospheric lightning scientist, commented that bead lightning is a well-known phenomenon.

Bead lightning has been reported most commonly to occur from one cloud to another, forming a discontinuous line of luminous images which persists for a time after the initiating normal linear lightning. The luminous images are of the same apparent size as the diameter of a linear lightning channel and appear to be nearly spherically shaped. Each image is separated from the next by an unilluminated region. The dark gap may have dimensions of a few diameters of the illuminated segments.

The bead lightning form is thought to evolve from an abnormal lightning channel between two clouds. The normal lightning discharge channel apparently decays into the series of disconnected luminous fragments. The complete bead lightning form, with its numerous segments, apparently occurs simultaneously and is not an image formed by a single moving illuminated object which has a periodic variation in brightness. It appears to observers to be a persistent illumination of a path followed by normal linear lightning and remains a relatively long time after the lightning flash has ceased. Lifetimes of such bead lightning occurrences are reported to be of the order of 1–2 sec.

Several specific characteristics distinguish bead lightning from

normal lightning and ball lightning. A quasiwave structure formed by the discontinuous line image is often reported. It appears as several cycles of a sinusoidal line. The quasiwave structure is not always present, while the dotted appearance is the commonly reported characteristic of bead lightning.

Some of the references to bead lightning available to this author are listed in Table 2.1.

2.2. *Bead Lightning Photographs*

The results of the present investigation have shown that bead lightning photographs are less common than generally assumed and that most photographs reported to be that of bead lightning are unreliable. True photographs of bead lightning may be even more infrequently published than those of ball lightning. All but three of the photographs identified as that of bead lightning were taken with simple still cameras and are therefore inherently suspect.

A photograph of a dotted illuminated path shown in Figure 2.1 was identified as that of bead lightning by Riggenbach-Burckhardt (1897) and later published by Wolf (1943b) and Benedicks (1954). It has been discussed several times since then and identified as both bead lightning and ball lightning. Riggenbach-Burckhardt (1897) published a second photograph which was also identified as that of bead lightning and is reproduced in Figure 2.2. The dotted appearance is coupled with a curved image line, but without the wave structure.

The validity of Figure 2.1 and Figure 2.2 was questioned by Behn (1903), who suggested that similar results could have been obtained by photographing a street lamp. A similar suggestion was discussed by Davies and Standler (1972) with regards to the photograph shown in Figure 5.3 which was reported to be the pulsating trace of a ball lightning.

Behn (1903) published a photograph that was intentionally made by camera motion with a street lamp in view. The photograph is reproduced here as Figure 2.3. As will be discussed in Chapter 5 with reference to Figure 5.3, European sodium vapor street lamps are driven by an alternating current at 50 Hz. At that rate, the sodium plasma can cool some 1000°C during the 0.01 sec between current peaks. The illumination is thereby modulated, giving a dotted appearance when photographed in a time exposure with a moving hand-held single-frame camera. Consequently, the photographs by Riggenbach-Burckhardt (1903)—Figures 2.1 and Figure 2.2—can only be labeled as doubtful and cannot be considered, in a scientific manner, to be of bead lightning.

Table 2.1. Bead Lightning References

Anon (1892d)	Mathias (1933a)
Anon (1892f)	Matthias and Buchsbaum (1962)
Anon (1960a)	Maurain (1948)
Anon (1964c)	McCrosky (1971)
Arrhenius (1903)	Meek and Graggs (1953)
Atkinson (1968)	Minin and Baibulatov (1969)
Beadle (1936)	Plante (1876d)
Beck (1927)	Pockels (1893)
Behn (1903)	Powell and Finkelstein (1969)
Benedicks (1954)	Powell and Finkelstein (1970)
Berg (1930)	Prochnow (1930a)
Bigelow (1907)	Prochnow (1930b)
Boll (1918)	Renou (1876)
Cade and Davis (1969)	Riggenbach-Burckhardt (1897)
W. Crawford (1895)	Rossman (1939a)
Fieux, Gary, and Hubert (1975)	Rossman (1939b)
Fouchet (1964)	Scheminsky and Wolf (1948)
Goodlet (1964)	Schmauss (1909)
von Hann (1926)	Schmauss (1910)
Hapke (1893)	Schmauss (1918)
Hasenauer (1930)	Schonland (1956)
Heidke (1932)	Seigner (1966)
Hildebrandsson (1909)	B. W. Smith (1868)
Hubert (1975a)	Stekol'nikov (1943)
Israel (1950)	Szpor (1977)
Jager (1892)	T. de Bort (1896)
B. J. B. Joule (1878)	Toepler (1917b)
Kapitza (1955)	Toepler (1954)
Kapitza (1962)	Tomlinson (1888a–c)
von Kilinski (1958)	Touchet (1931)
Lewis (1963)	Uman (1962)
Luizet (1908)	Uman (1968b)
Malan (1961)	Uman (1969)
Mathias (1928b)	Voitsekhovskii and Voitsekhovskii (1974)
Mathias (1930b)	Voitsekhovskii and Voitekhovskii (1975)
Mathias (1931a)	M. Wilson (1865)
Mathias (1931b)	F. Wolf (1943b)
Mathias (1931c)	G. A. Young (1961)

A photograph by Seigner (1966) similar to the reported characteristics of the bead lightning image is shown in Figure 2.4. The dotted image was reported to have occurred with the normal linear lightning. The trace of the bead lightning may be observed to be free of the forked nature of the normal lightning discharges. This behavior, being so dissimilar to normal lightning, is one characteristic that has set bead lightning apart for specific notice by observers. However, the particular trace in Figure 2.4 is somewhat questionable because of the partial

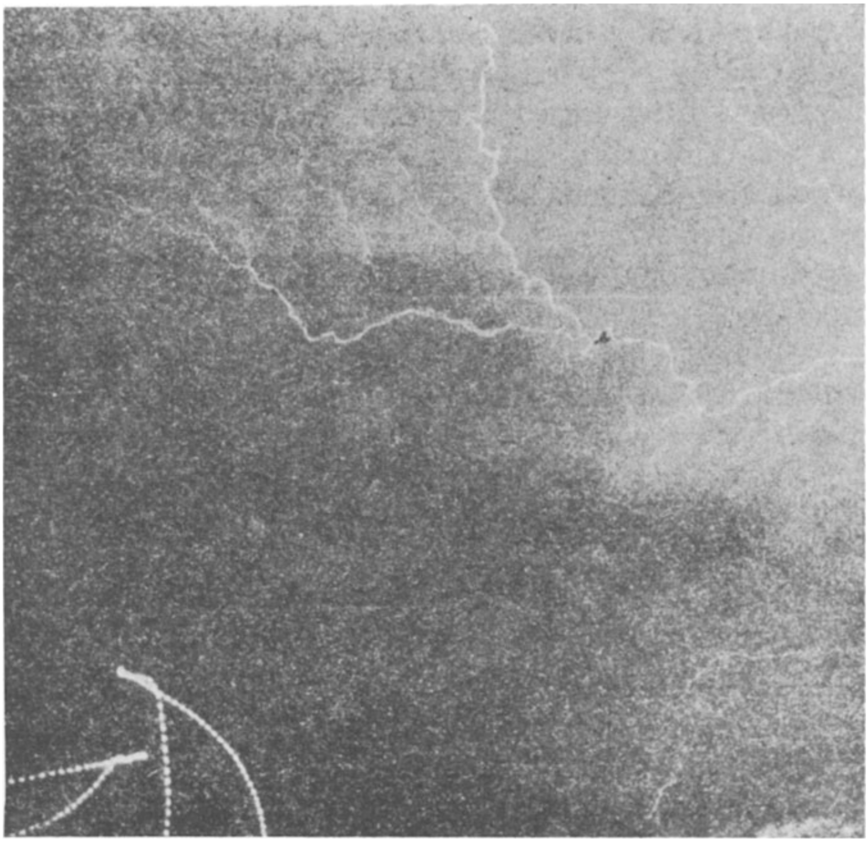

Figure 2.1. Still camera photograph taken during a thunderstorm showing a trace of varying brightness identified as that of bead lightning. The accuracy of this identification is questioned because of Figure 2.3. Reprinted from A. Riggenbach-Burckhardt, "Perlschnurblitz," *Meteorol. Zeit.*, **14,** 1897, p. 62. Enlargements of the dotted path were later published by S. A. Arrhenius, *Lehrbuch der Kosmischen Physik, I,* S. Hirzel, Leipzig, 1903, p. 772; by F. Wolf, "Das Gewitter und seine Entladungsformen, II Teil: Kugelblitz und Perlschnurblitz," *Naturwiss.*, **31,** 1943, p. 215; by C. Benedicks, "Theory of the Lightning-Balls and its Application to the Atmospheric Phenomenon called Flying Saucers," *Arkiv foer Geofysik,* **2,** 1954, p. 1.

duplicate trace on the upper center portion of the photograph: This shape is apparently a duplicate of the main bead lightning image. It is unlikely that two or more discharges could be so controlled by the atmospheric electic fields and widely separated space charge densities. Thus Figure 2.4 is considered questioable, possibly having been caused by camera motion, and not representative of a true bead lightning.

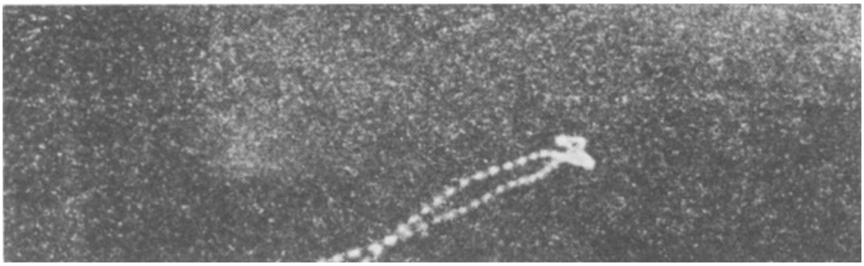

Figure 2.2. Still camera photograph taken during a thunderstorm showing a trace of varying brightness identified as that of a bead lightning. This identification is questioned because of Figure 2.3. Reprinted from A. Riggenbuch-Burckhardt, "Perlschnurblitz," *Meteorol. Zeit.*, **14,** 1897, p. 62 and produced by C. Benedicks, "Theory of the Lightning-Balls and Its Application to the Atmospheric Phenomenon called Flying Saucers," *Arkiv foer Geofysik*, **2,** 1954, p. 1.

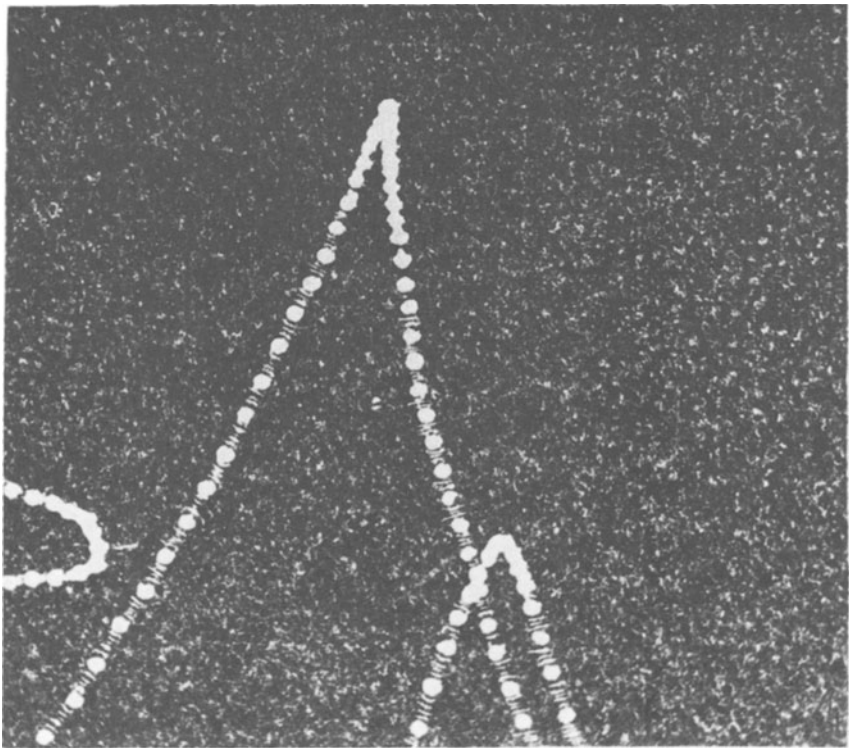

Figure 2.3. Still camera photograph of a street lamp taken while the camera was intentionally moved to create an intensity-modulated trace. This figure casts doubt on the identification of Figures 2.1 and 2.2 as being those of bead lightning. Reprinted from U. Behn, "Über Photographien von Perlschnurblitz," *Meteorol. Zeit.*, **20,** 1903, p. 379.

Figure 2.4. Still camera photograph taken during a thunderstorm showing an intensity-modulated trace identified as that of a bead lightning. The repeated traces in the upper central portion of the figure suggest that this photograph could have been made by camera motion. Reprinted with permission from Akademische Verlagsgesellschaft, Geest and Portig K.-G., Leipzig, after R. Seigner, "Perlschnurblitz," *Wetter und Leben*, **18,** 1966, p. 54.

Figure 2.5, from Schmauss (1909), is another reported example of bead lightning. The lengths of the small bright images it may be noticed, become longer on going from left to right. The trace might suggest variable motion of the source or motion perpendicular to the plane of the page. This image should be contrasted to that of Figure 5.3, which was reported to have been made by a singular ball lightning. The Schmauss (1909) photograph was also published by Schmauss (1910) and von Kilinski (1958). The photograph is again questionable because of the findings of Behn (1903).

Only two photographs have been found that exhibit the quasiperiodic wave structure usually attributed to bead lightning. The first photograph, shown in Figure 2.6, was apparently originally published

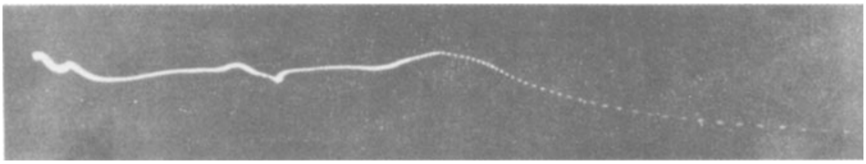

Figure 2.5. Still camera photograph taken during a thunderstorm showing an intensity-modulated trace identified as that of a ball lightning. The photograph resembles that in Figures 2.3 and in Figure 5.3 in some respects. Camera motion is suspected. Reprinted from A. Schmauss, "Perlschnurblitz," *Physik. Zeit.*, **10,** 1909, p. 968 and reproduced by A. Schmauss, "Perlschnurblitz," *Meteorol. Zeit.*, **27,** 1910, p. 83, and by K. von Kilinski, *Lehrbuch der Luftelektrizitat,* Akademische Verlagsgesellschaft, Geest and Portig K.-G., Leipzig, 1958.

by Prochnow (1928) and reproduced later in Prochnow (1930). The bead lightning dotted appearance is subdued and may be completely lacking. The intensity modulation is barely observable and may reflect film or development characteristics. Walter (1929) questioned the validity of this photograph, suggesting once again camera motion and a street lamp.

The second photograph showing a wavelike image is reproduced here as Figure 2.7. The photograph was originally published by Scheminzky and Wolf (1948) and described by them as an authentic bead lightning photograph. It was taken by F. Scheminzky with a hand-held camera but not observed at the instant the photograph was made. The negative was closely inspected by a Professor Eggert of Leipzig, but few definitive findings were reported. The dotted trace was apparently a natural part of the negative but its interpretation could not be exactly stated. M. Toepler also evaluated the Scheminzky photograph and considered it to be that of a bead lightning. Singer (1971) expressed doubt since the bead lightning event was unwitnessed.

Several drawings of bead lightning have also been published over the years. One by M. Toepler (1916) is reproduced here as Figure 2.8

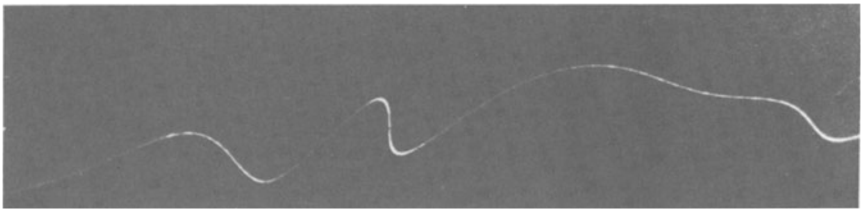

Figure 2.6. Still camera photograph by Th. Mettlers showing a quasisinusoidal trace identified as that of a bead lightning. Camera motion is suspected. Reprinted from O. Prochnow, "Zur Blitzforschung," *Physik. Zeit.*, **31,** 1930, p. 335. The photograph apparently originally appeared in O. Prochnow, *Erdball and Welfall,* H. Bermuhler, Berlin, 1928.

Figure 2.7. Still camera photograph by F. Scheminzky in 1933 of an image identified as that of a pearl lightning. The beginning and termination are marked by the arrows. The pearl lightning event was not witnessed by the photographer, and doubt as to its validity has been expressed. Reprinted with permission of Springer-Verlag, New York. The photograph was published by F. Scheminzky and F. Wolf, "Photographie eines Perlschnurblitzes," *Sitzung. Akad. Wiss. Wien, Math.-Maturwiss. Klasse,* IIa, **156,** (1,2), 1948, p. 1.

and is noteworthy in that the observer was a noted electrical scientist of his period. The photograph was discussed and reprinted by Wolf (1943b) and Scheminzky and Wolf (1948). Toepler (1916) apparently discussed the observation and his interpretation of the pearl lightning event. That is, end-on observation of a normal lightning discharge over a random path in space might be interpreted as a string of luminous beads by an observer. However, evolution of the linear stroke to the dotted form has been reported by observers of the events. The conflict between reports and photographs which may be interpreted many ways indicate the need for automatic, remote-controlled, multiple-camera and rapid-exposure-time film sequences of such events.

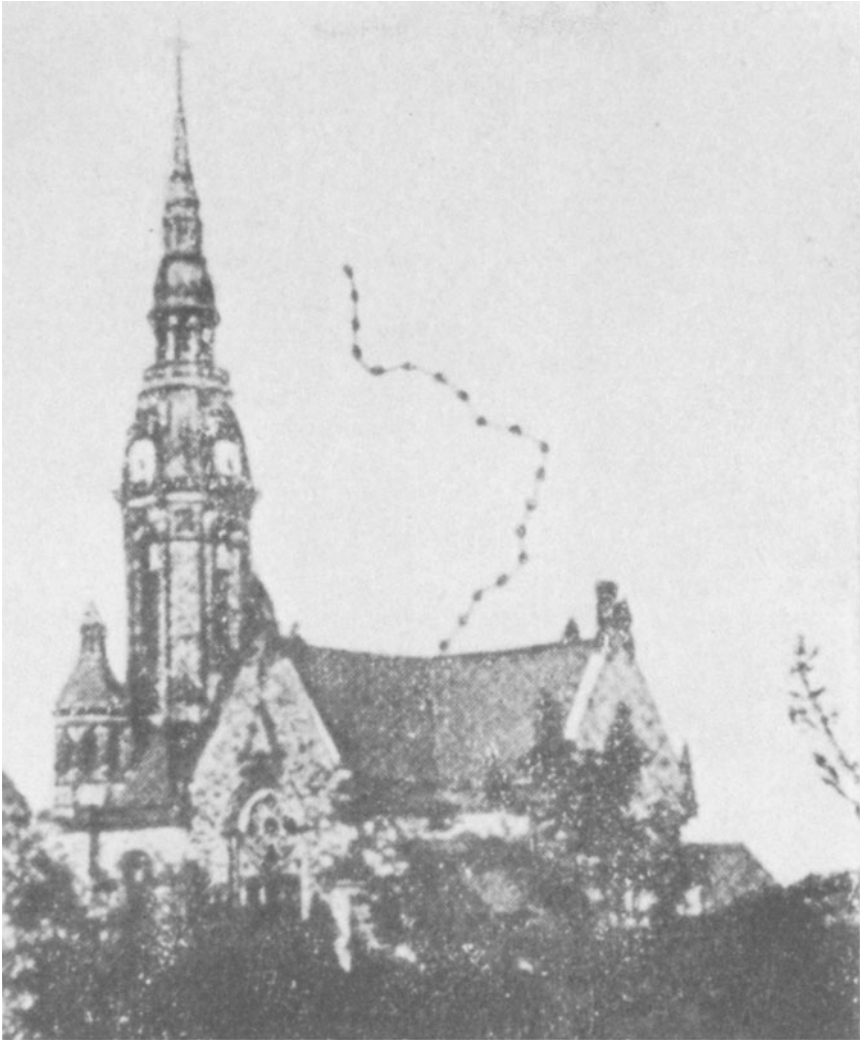

Figure 2.8. Drawing of a pearl lightning observed by the scientist M. Toepler in Dresden in 1916. Reprinted with permission of *Die Naturwissenschaften.* The drawing was apparently originally published by M. Toepler, "Unavailable—Title Unknown," *Abh. Naturwiss. Ges. Isis.,* Dresden, 1916 and reproduced by F. Wolf, "Das Gewitter und seine Entlandungsformen. II. Teil: Kugelblitz and Perlschnurblitz," *Naturwiss.,* **31,** 1943, p. 215 and by F. Scheminzky and F. Wolf, "Photographie eines Perlschnurblitzes," *Sitzung. Akad. Wiss. Wien, Math.—Naturwiss. Klasse,* IIa, **156** (1,2), 1948, p. 1.

A striking photograph of a possible bead lighting is shown in Figure 2.9 after Matthias and Buchsbaum (1962). The original photograph was in color and the lightning image was white. The camera was placed in a darkened room and pointed toward a thunderstorm through a window. The camera was inclined to the horizontal at an angle of about 15°. Six frames were exposed for 15 min each. Four were blank, one showed a normal lightning stroke, and the other showed the photograph in Figure 2.9.

The image has a quasidotted appearance, is lacking the wave string appearance, is relatively straight, and is of finite length. The segments are not at all similar to one another. The photograph has been reproduced in Anon (1964c) and Lewis (1963), where it was termed an example of either a ball lightning or a bead lightning.

A similar beaded discharge was photographed by Young (1962), also a scientist, and reproduced by Atkinson (1968), Cade and Davis (1969), and Powell and Finkelstein (1970). The photograph is shown in Figure 2.10. The discharge occurred prior to a storm at sea from a cloud to a water spout and resulted from an intentionally detonated explosion. This particular photograph is one of the few examples of induced lightning available as well as being one of the few examples of bead lightning.

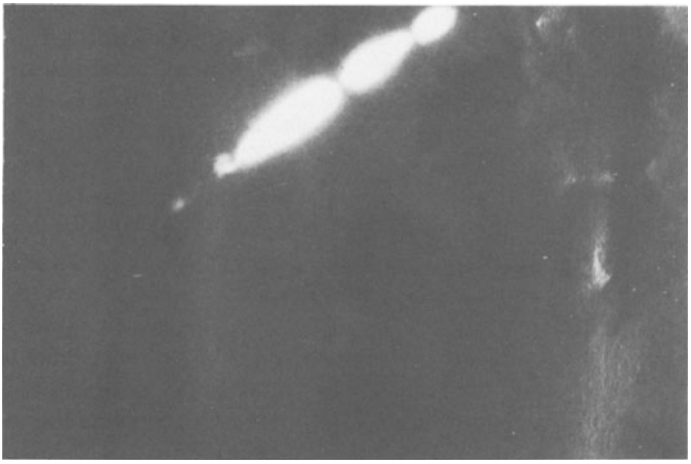

Figure 2.9. Still camera photograph taken during a thunderstorm showing a segmented illuminated path of a trace identified as that of a pinched lightning. The photograph is considered to be one of the few examples showing a bead lightning trace. Reprinted with permission with *Nature,* MacMillan Journals, London, after B. T. Matthias and S. J. Buchsbaum, "Pinched Lightning," *Nature,* **194,** 1962, p. 327 and reproduced by H. W. Lewis, "Ball Lightning," *Sci. American,* **208,** 1963, p. 106; by Anon, "New Theoretical Model for Ball Lightning," *Science News Lett.,* **86,** 1964, p. 199; and by R. A. Leonov, *The Riddle of Ball Lightning,* Izd-Vo, Nauka, Moscow, 1965.

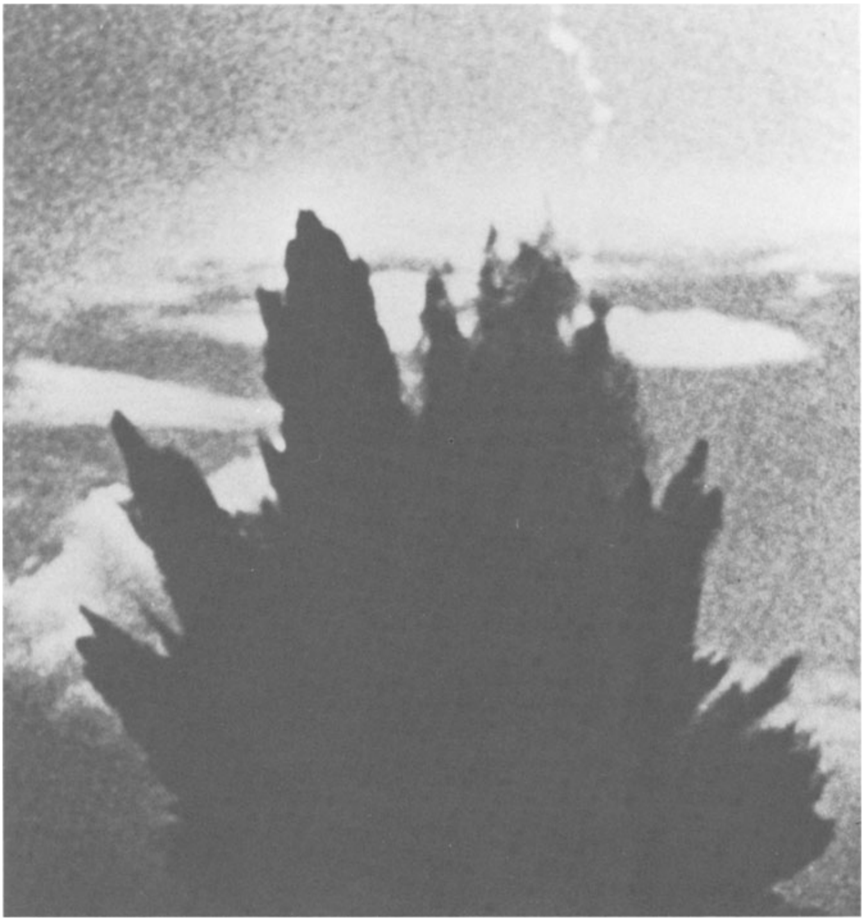

Figure 2.10. Photograph of a triggered lightning discharge to a water plume during Naval experiments at sea. A series of photographs was made. The photograph is considered to show an example of a bead lightning trace. Reproduced with permission from U.S. Naval Surface Weapons Center, originally from G. A. Young, "A Lightning Strike of an Underwater Explosion Plume," U.S. Naval Surface Weapon Center, TR 61-43, Feb. 1962, and later reproduced by B. W. Atkinson, "Riddle of Ball Lightning," *Geographical Magazine,* **41,** 1968, p. 204; by C. M. Cade and D. Davis, *Taming of the Thunderbolts,* Aberland-Schuman Ltd., New York, 1969; and by J. R. Powell and D. Finkelstein, "Ball Lightning," *American Scientist,* **58,** 1970, p. 262.

The lightning stroke to the water plume was recorded simultaneously by two cameras. One had 35-mm film with a frame rate of 23.8 per second and the other had 35-mm film with a frame rate of 109 per second. Both cameras simultaneously recorded sequential lightning strokes to the water plume. Four successive lightning strokes were recorded. All strokes apparently followed the same path and each secondary discharge occurred before the previous discharge had completely dissipated. The beadlike appearance of the path appeared as each discharge faded. The bead structure was recorded by both cameras.

Discussions and photographs of other bead lightning events caused during induced lightning experiments were published by Fieux and Hubert (1976) and by Fieux, Gary, and Hubert (1975). Lightning discharges were induced by launching small rockets which trailed a metal wire from the ground. A conductive path between an electrified cloud and the ground was thereby created. A triggered discharge resulted which evaporated the wire and also allowed successive strokes to occur. The discharges were in the kiloamp range for a few tenths of

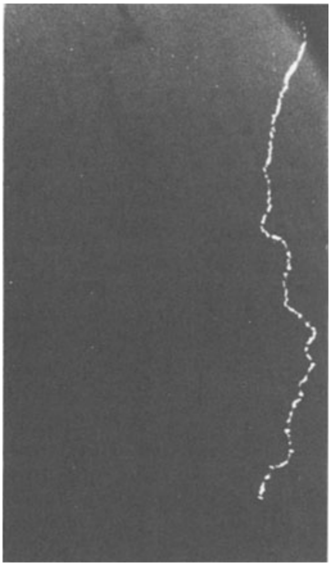

Figure 2.11. Movie camera photograph of the persistent illumination remaining after a triggered lightning discharge. The beadlike structure remained for about 0.3 sec. Reproduced with permission of P. Hubert and C.E.N. Saclay, France, after P. Hubert, "Tentative pour Observer la Foudre en Boule dans la Vaisinage d'Eclairs Declenches Artificiellement," Rapport DPH/EP/76/349, 5 Mai 1975, Commissariat à l'Energie Atomique, Service d'Electronique Physique, Center d'Etudes Nucléaires de Saclay, France.

Figure 2.12. Still camera photograph made in the mid-USA at one of the automated sites operated by the Smithsonian Astrophysical Observatory. The camera was equipped with a chopped shutter which caused the aperture to open for 25 msec, close for 38 msec, and required 6 msec to open or close. Persistent or moving illuminated objects would be recorded as a series of dashed lines. Bead lightning was identified as the probable cause of this lightning image. Reprinted with permission of the Smithsonian Institute, from R. E. McCrosky, *"Phenomenology of Bead (?) Lightning Event,"* unpublished report of the Smithsonian Institution Astrophysical Observatory, Nov. 1971.

a second. An upward discharge velocity of about 10^4 m sec^{-1} was recorded. The photographs were made with 35-mm movie film (48–150 frames per second) and with single-frame still film as well.

It was occasionally found that a triggered lightning channel would persist for a period after the main discharge. A beaded appearance was formed which lasted for about 0.3 sec. The individual beads had a diameter of about 40 cm. One example of the beaded structure is shown in Figure 2.11. Other triggered channel photographs are shown in Figures 7.2 and 7.3 after Hubert (1975a) and discussed in Chapter 7, Section 7.2.

Lightning photographs are occasionally made during investigation of other occurrences. The photographs shown in Figures 2.12 and 2.13 are two examples of those made by automated camera stations in the Midwest USA which were operated by the Smithsonian Astrophysical Observatory to study meteor events. The cameras were equipped with chopping shutters which exposed the film at a basic rate of 13.33 Hz so that the shutter was open for about 1/3 of the cycle. The camera

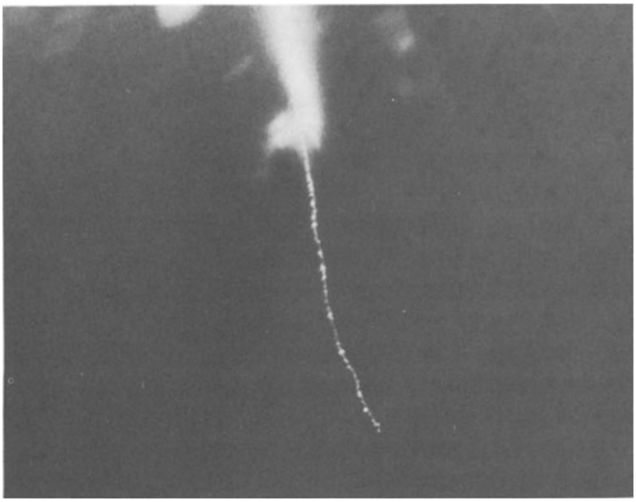

Figure 2.13. Still camera photograph made in the mid-USA at one of the automated sites operated by the Smithsonian Astrophysical Observatory. The camera was equipped with a chopped shutter which caused the aperture to open for 25 msec, close for 38 msec, and required 6 msec to open or close. A moving illuminated object would be recorded as a series of dashed lines. Bead lightning was identified as the probable cause of this lightning image. Bead lightning was found to originate from the lower end of a lightning channel. Ball lightning was found to originate from the side of the channel rather than the end, as shown in Figure 5.16. Reprinted with permission of D. R. Tompkins, after D. R. Tompkins and P. F. Rodney, *Photographic Evidence of Ball Lightning,* Terrene Corp., Refugio, Texas, Oct. 1977.

aperture was open for 25 msec, closed for 38 msec, and required 6 msec to open or close.

A moving luminous event which would occur within the 25 msec period would be fully recorded on the film. A typical lightning step leader from cloud to ground would occur in about 20 msec, as measured by Krider, Weidman, and Noggle (1977). The return stroke would take less than a millisecond. A dart leader requires only a few milliseconds to go from cloud to ground. The only lightning stroke that occurs slowly compared to the shutter period would be the step leader. Normal lightning strokes would, therefore, be expected to appear without interruption, or with only one interruption, on the film.

A moving luminous event that persisted for many chopping periods would appear as a series of dashed images. Consequently, dashed traces might be interpreted as bead lightning or ball lightning events. Additionally, a moving point—a ball lightning—would leave a trace somewhat different from a persistent lightning channel—a bead lightning.

McCrosky (1971) reported on the conditions surrounding the recording of the photograph shown in Figure 2.12. Lightning activity was also simultaneously recorded by four cameras at the station. The dashed image was interpreted as having been caused by a bead lighting since a ball lightning interpretation would have required an upward motion of 20 m sec^{-1} and the presence of many subsidiary balls. The image was therefore identified as a bead lightning illumination, persisting after a cloud-to-ground stroke. The apparent motion corresponded to the luminous areas having been swept along by the storm wind, about 20 m sec^{-1}. The stroke extended over 1 km in length and the bead persistence was 75 to 300 msec. The bead size was estimated at from 50 cm to several meters in diameter.

Tompkins and Rodney (1977) and Tompkins, Rodney, and Gooding (1975) evaluated about 12,000 photographs from the Prairie Meteorite Network records. Over 120,000 lightning flash images were identified. Twenty-two photographic images were interpreted as having been caused by bead lightning events. One is shown in Figure 2.13.

Tompkins and Rodney (1977) determined that a bead lightning image would be directly tangent to the tip of the continuous lightning leader path. A ball lightning, however, would appear to exit from the side of a lightning channel. Refer to Figure 5.16, which was also uncovered by Tompkins and Rodney and identified as a ball lightning image. Bead lightning and ball lightning images are also dissimilar in that a ball lightning image spacing would be determined by the chopping shutter and should be regular. A bead lightning image spacing would be irregular.

The phenomena recorded in Figures 2.12 and 2.13 are unusual; only 22 occurrences in over 20 years of observation and 500,000 camera-hours of exposure time. The interpretation of these photographs as bead lightning is difficult and involves assumptions regarding the complex behavior of dart and stepped leader lightning strokes. Dr. Tompkins indicated to this author that while the images appear as one would expect bead and ball lightning to appear, the interpretation cannot be definite because of variations in the consistency of the path traces.

A bead-lightning-like discharge has also been produced during high-voltage discharge experiments and the luminous channel recorded on movie film. One example is shown in Figure 2.14, which was obtained by R. Golka of Project Tesla, Wendover, Utah and J. Schneider of Technology Scientific Sciences, Dayton, Ohio under the auspices of USAF/AFDL contract No. F33601-78-D0042. The picture shown is one frame of a series of five frames taken with a 16-mm movie camera at

a frame rate of 30 frames sec^{-1}. The phenomenon apparently existed for only about 0.16 sec.

The discharge was created with a set of Tesla coils which were constructed by R. Golka to be identical to those used by N. Tesla during the period 1899–1900 but up-dated with modern materials and excitation equipment. The coil developed about 2.5×10^7 V and produced a pulse energy of about 12 J. Refer to Chapter 7, Section 7.5 for more discussion on the experiments of Tesla.

The recent tests were conducted in air as part of a series of experiments to determine the effects of high-voltage discharges to aeronautical equipment. The appearance of the bead-lightning-like structure was unintentional and surprising. Similar forms have also been unintentionally produced and photographed during other tests. The phenomenon shown in Figure 2.14 was not noticed by the observers during the tests but discovered on the movie film after the completion of the experiments.

The phenonmenon was interpreted as the residue of a normal high-voltage discharge channel created during the experiments. Other structures, such as fireball-like forms, were reported by Tesla (1978) as occasionally appearing during his high-voltage experments in 1899–1900. Tesla attributed the phenomena to preferred heating of a discharge path by another discharge followed the initial discharge that created the path and defined a channel of partial ionization. A simple analysis, shown in Chapter 7, Section 7.5, indicates that a fireball so formed could have dimensions similar to those observed. The observations of Tesla have also been evaluated by Bass and Golka (1976).

The bead lightning photographs shown in this chapter have been subjected to examination and critical analysis by this author and other investigators as well. Most of the photographs have been evaluated with reference to other photographs of known phenomena. Our conclusion is that most of the photographs reported to be of a bead lightning are at least questionable, and should probably be dismissed. A number of the photographs have been labeled as definitely erroneous. The photographs are critically evaluated in Chapter 6.

A major factor in the difficulty of evaluating such photographs is the means used to record the phenomena. Single-frame camera photographs can easily be misinterpreted because of the small amount of information available in a single photograph. The preferred manner for the recording of a possible bead lightning event is with fast-film-rate movie cameras and simultaneous observers. Serious study of the phenomena should include multiple cameras from various angles with

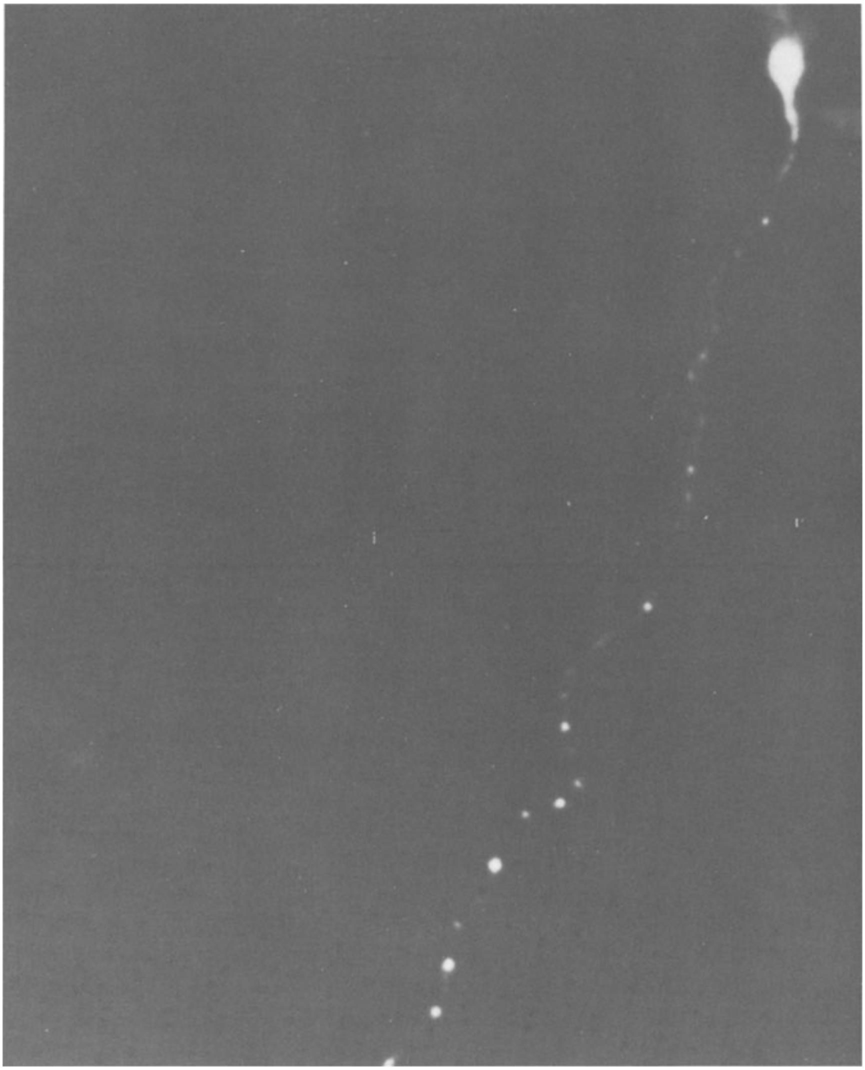

Figure 2.14. Photograph of a bead-lightning-like discharge channel produced with a large Tesla coil at a potential of about 2×10^7 V with a discharge energy of about 12 J per pulse. The photograph is one of five frames taken with a 16-mm movie camera with a film rate of 30 frames per sec. The bead-lightning-like structure was the apparent residue of a high-voltage discharge path and lasted only about 0.16 sec. The previously unpublished photograph was made by R. Golka of Project Tesla, Wendover, Utah and J. Schneider of Technology Scientific Services, Dayton, Ohio under the auspices of USAF/AFDL contract No. F33601-78-D0042 and is reproduced with their permission.

automated sequences if full-time presence of observers is not possible. The Prairie Meteorite Network is one example of this scheme.

2.3. Bead Lightning Origins

Bead lightning is thought to result from a lightning channel that develops a periodic longitudinal intensity oscillation due to some perturbing influence. The channel decays to become a series of almost uniformly separated areas with a persistent luminosity. This concept has been considered by Toepler (1917a), who assumed that bead lightning segments developed at stress points in the lightning channel. Toepler proposed a formation sequence as shown in Figure 2.15.

A possible example of this formation sequence is shown in the photograph made during a lightning storm by D. Roguet and A. Roguet in 1930. The photograph was reproduced by Tochet (1931), who briefly discussed the meteorological conditions at the time of the event. The specific photographic conditions, such as exposure time, are not known. Evaluation of the negative was not possible. The photograph is shown here as Figure 2.16. There were apparently six successive lightning strokes separated in space and time. The sixth stroke evolved into the bead form. Evaluation by Touchet of the dotted images by enlarging that portion of the photograph indicated that the bright segments were all about equivalent in size and appearance and separated by almost equal dark spaces. He also reproduced the enlarged photograph.

Touchet noted that the appearance did not completely agree with the theory that bead lightning was the eye's interpretation of a normal stroke following a tortuous path so that the channel would not be totally visible. The luminous segments and the dark regions of the beaded

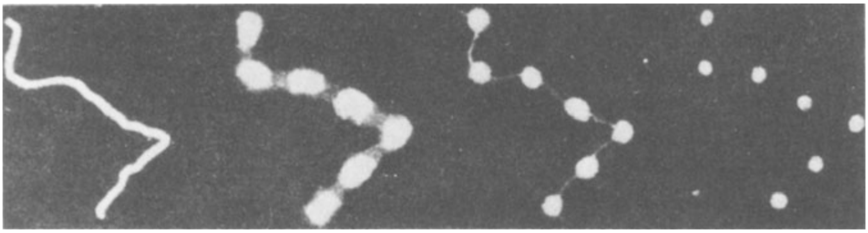

Figure 2.15. The development of bead lightning from the decay of an abnormal lightning channel under longitudinal stress is illustrated by the drawing by M. Toepler, "Zur Kenntnis der Gesetze der Bildung von Leuchtmassen (Perlen) bei Perlschnurblitz," *Meteorol. Zeit.*, **34,** 1917, p. 225.

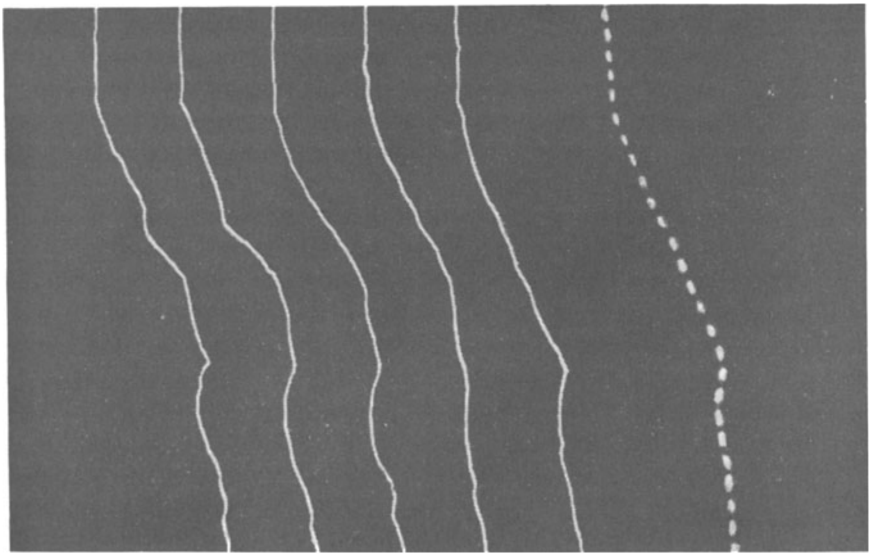

Figure 2.16. Still camera photograph of a bead lightning which apparently developed from a linear stroke. Six successive strokes were recorded; only the last one evolved into the bead form. The photograph was originally taken by D. Roguet and A. Roguet in 1930 and published by E. Touchet, "Éclair en Chapelet," *Bull. Soc. Astron. Fr.*, **45**, 1931, p. 84.

channel are fairly regular, suggestive of the characteristics normally assumed for bead lightning. The photograph of Figure 2.16 cannot be termed unquestionably valid as evaluation of the negative and full knowledge of the event conditions are not known.

The laboratory study of current discharges has shown an unusual feature termed the "pinch effect." A current filament can be confined in the longitudinal dimension by its own self-magnetic field. Perturbations in the magnetic field, the channel axis, or the space charge densities can cause discontinuities in the shape of the current channel. The cylindrical geometry of the current filament may be caused to be varied along the channel axis with time. The pinch effect has been related to bead and ball lightning formation and persistence by Uman (1962), Uman and Helstorm (1966), and Uman (1969).

The pinch-effect experiments have been conducted at low pressures, normally rom 10^{-3} to 1 mm Hg pressure, and have dissipated 10^3 J of energy at 10^4 V. The experimental conditions are limited by the inability to cause high-current, atmospheric pressure, lightning-like discharges. The plasma pinch is dependent upon a high-current flow, of order 10^4 A, to initiate the magnetic compressional processes.

The confinement of a current filament by its own self-magnetic field has been considered by Spitzer (1962) and Tanenbaum (1967). The fields of a current filament are normally defined in cylindrical coordinates. A plasma confined by its own B_θ field component is termed a self-pinched plasma and one confined by an external B_Z field componet is termed externally pinched. The self-pinched discharge is occasionally termed a longitudinal pinch as the current is along the longitudinal dimension. The externally pinched discharge is termed an azimuthal pinch or a theta pinch. We are concerned here with the self-pinched or longitudinal pinched current discharge.

The self-pinch condition is a result of the interaction of the electrons with the magnetic field caused by the current flow. The magnetic field lines about a linear current form concentric circles in a plane perpendicular to the line current. The electrons experience a force defined by the relation

$$\mathbf{F} = -e(\mathbf{E} + \mathbf{u} \times \mathbf{B}) - m\nu\,\mathbf{u} \tag{2.1}$$

where $\mathbf{u}$ is the electron velocity, m is the electron mass, e is the electron charge, ν is the electron collison frequency with particles in the medium, and $\mathbf{E}$ and $\mathbf{B}$ are the electron and magnetic field intensities.

The $\mathbf{u} \times \mathbf{B}$ force is directed inward in the radial $-\mathbf{r}$ direction and can cause inward electron motion, the pinch. A formal relationship may be deduced with the aid of Maxwell's equations and the definition of the current, $\mathbf{J} = Ne\mathbf{u}$, where N is the electron density. The result verifies the general $-\mathbf{r}$ force but does not establish a temporal or axial position relation.

Uman (1962) noted that in the laboratory plasma pinch, the current cylinder contracts and oscillates independently of axial position. In an atmospheric lightning discharge, this might not be the case. As a result of periodic variations with height of various atmospheric–electrical properties such as space charge and electric fields, axially irregular pinch conditions could exist. Uman speculated that under certain conditions the radius of the lightning channel could be approximated by a function of the form

$$R(z, t) = Af(t)\left(1 + k\sin\frac{2\pi Z}{\lambda}\right) \tag{2.2}$$

where Z is the axial position, ground to cloud, and λ is determined by the pinch time and properties of the current column.

It was argued that the pinch effect would occur first near the ground where the high current occurs initially. The pinch would

propagate upward as the current flow increases from ground to cloud. The wavelength of the disturbance would be determined by the pinch time and the propagation velocity. If the pinch time is of the order of microseconds and the velocity of the order of the speed of light, then the fundamental wavelength is of the order of 10 m.

In general, any transverse waves propagating up and/or down the current column will have random phases and will produce no coherent effects. It is possible to speculate that, under certain conditions, standing waves could be produced. These standing waves could in turn modulate the plasma column dimensions. The modulation would certainly modify the radius of the column and would have a temporal and azimuthal dependence. Such a modulation might be driven by a small perturbation at some azimuthal position.

R. H. Hill (1963) presented evidence that periodic oscillations do occur within the lightning channel. The study evaluated the heating effects of a lightning discharge on a grounded electrode. The surface of the electrode was found to have been heated to its liquid temperature by the current flow. The curvature of the electrode surface was modified by the electromagnetic forces at the column–electrode interface. The electrode surface was modified by the thermal conditions to show a pattern of closely spaced concentric rings.

The concentric ring patterns were evaluated under high-power microscopes. The separation between adjacent ring peaks appeared to be consistent from one sample to another. The spacing was about 4×10^{-4} cm. It was suggested that the concentric rings resulted from ripples set up in the molten metal electrode surface by internal discharge column acoustical oscillations. The frequencies of the acoustic oscillations were computed by Hill as being of order 10^6 Hz.

It should be recognized that although these oscillations were in the radial dimension of the electrode–column interface, axial propagation could not be determined. These oscillations alone could not be expected to drive a plasma pinch. It does serve to illustrate that oscillations can and do exist within a lightning channel and that the suggestion by Uman (1962) may be valid.

In correspondence with Professor Uman, he indicated that, on the basis of more recent data, the normal lightning currents could not be expected to be large enough to drive the pinch effect. However, if the current density were high enough, plasma pinch conditions might be initiated and a bead lightning structure might result.

The source of bead lightning is still an object of speculation.

3

Ball Lightning

3.1. General Characteristics

Ball lightning as well as bead lightning is considered by many to be an atmospheric electrical phenomenon observed during thunderstorm activity. It is reported to be a single, self-contained entity that is highly luminous, mobile, globular in form, and appears to behave independently of any external force. The ball lightning phenomenon is also known by many other terms: globular lightning, balls of fire, lightning balls, *kugelblitz, globes de feu, tonnerre en boule, coup de foudre en boule, foudre globulaire, éclair en boule, fulmini globulaire, sharovoyi molnii, kugelynet,* and *klotblixtar,* to name a few.

The properties and characteristics of ball lightning have been deduced by a number of researchers from surveys and quasistatistical analyses of collected reports. The studies include those by Anon (1921), Arago (1854), Barry (1966, 1967a), Brand (1923, 1971), Charman (1979), Dewan (1964), De Jans (1910), Jeffreys (1921), Mathias (1924a–d), McNally (1966), Rayle (1966), and Sauter (1895).

References to ball lightning may be found in numerous publications and writings dating back hundreds, even thousands, of years. Singer (1971), for example, provided a general discussion of historical observations ranging from the sixth century A.D. to comments by eminent scientists of the eighteenth, nineteenth, and twentieth centuries. Bougon (1902) and Flammarion (1904a) both discussed particulars of observations in the sixth century as contained in the works of St. Gregory of Tours. Flammarion (1904a) also reproduced a photograph of the painting *La Masse de Saint Martin* from the Louvre museum, which pictures a ball of fire (globus igneus) during a religious ceremony. Algeo and Pyles (1966) referred to curious lightning observations, perhaps ball lightning, which were contained in the *Anglo-Saxon Cronicle*

in 793 A.D. Turner (1962) discussed the observations of lightning phenomena and St. Elmo's Fire as found in the writings of G. Plinus Secundus in 77 A.D.

Flammarion (1904a) discussed over 20 ball lightning observations, the earliest in 1557. Brand (1923) included literal transcriptions of some 215 first-person observations of ball and bead lightning. Most occurred in the nineteenth and twentieth centuries, although one in 1744 was also discussed. Sauter (1895) also discussed several hundred observations from 1742 to the late nineteenth century. Arago (1854), on the other hand, included brief reference to over 30 reports from 1718 to the mid-nineteenth century.

A number of early first-person observations prior to 1850 are readily available to the reader. These include those of Anon (1670, 1692, 1800), Argyle (1838), Borlase (1753), Brereton (1781), L. E. Chalmers (1751), Child (1755), Cooke (1742), Decerfz (1847), Derham (1729), Eliot (1773), Faraday (1833, 1839), Gordon (1742/43), W. Hamilton (1795), R. Hare (1828, 1840), Hebert (1847), Hugueny (1845), King (1773), Lining (1754), C. Mason (1742/43), Nicholson (1774), Nixon (1750), Palmer (1752), Paradise (1773), Parisot (1821), Pilaye (1843), Wainhouse and Pitcairn (1773), Wasse (1725), W. Watson (1754), and Weekes (1841). Other references to observations made several hundred years ago have not been available to this author but are also noted in the reference list in Chapter 8.

The characteristics of ball lightning are such as to distinguish it from other natural electrical phenomena that occur in the atmosphere. The specific properties and behavior also evoke emotional and occasionally heated discussions. The characteristics that will provide a general physical description of ball lightning will be discussed in this chapter. Those characteristics that may be used to infer specific source properties are discussed separately in the next chapter.

The general characteristics of ball lightning may be categorized according to the various physical properties observed, detected, and subsequently reported. These include the following:

shape	sound	decay
size	odor	lightning dependence
color	damage	attraction to enclosures
structure	heat	altitude
motion	lifetime	

The various surveys of the numerous reports of the ball lightning events have indicated many similarities in the reported properties as

well as several distinctive variances. Such variances and conflicts occur as a result of the erroneous identification of other phenomena, such as St. Elmo's Fire, as a ball lightning event. St. Elmo's Fire is the visual result of a coronal discharge from a fixed grounded object in the presence of an atmospheric electric field and not a form of ball lightning. Such erroneous reports have been eliminated from the general description here.

3.2. Observed Properties

Shape and Size. Ball lightning has been reported with spherical, oval, teardrop, and even rod shapes. Dimensions of the spherical or oval-shaped ball lightning vary from a few centimeters to several meters in diameter. The most common diameter reported is 10–40 cm. Reports on the size of the teardrop shape indicate smaller dimensions, usually less than 20 cm. The rod shape is least reported. The ratio of its length to dimeter is usually less than 2 : 1, with 15 cm the most commonly reported diameter. Most observers estimated dimensions by comparing the ball lightning with some familiar object. A spherical or oval shape with a diameter less than about 40 cm is most frequently reported.

The dimensions of ball lightning are of importance for the calculation of its energy density and the postulates regarding formation mechanisms. There is some confusion about the actual diameter as one's perception of a light source diameter is usually greater than its actual size. Perceptual effects and the influence on observers and their reports are discussed in Chapter 6, Section 6.3. If we could verify that the diameter of 15–40 cm is overestimated by some factor, then the calculated and deduced properties that depend upon the diameter, such as the energy density, would decrease in an appropriate manner. Refer to Chapter 4, Sections 4.1 and 4.2.

Color. Most ball lightning reports indicate the object as having had a red, red-yellow, or yellow color. Other colors, including white, green, and purple were occasionally reported. Blue and blue-white colors are associated with reports of St. Elmo's Fire. There is no apparent positive correlation between color and shape—each shape has been reported as having several colors. The purple or violet color, however, is somewhat moe frequently associated with the rod shape.

A color change with time was reported by only a few of the observers. These changes fall into three categories: red to white, violet to white, and yellow to white. The reports agree that the final color was

dazzling or bright white and that the ball disappeared noisily after the color change. Color changes were reported, for example, by Jennings (1962), Mathias (1924a–d), and Renou (1876).

The specific color of a ball lightning may be indicative of trace amounts of foreign material within its gaseous medium. Several experimental results have shown that colors are related to impurities present at the time of ball ignition or to impurities that develop during the lifetime. Barry (1968a,c) reported a yellow and yellow-red color which was associated with a low-density spherical hydrocarbon flame. Powell and Finkelstein (1969, 1970) reported white and yellow-white colors with normal air excited by radiofrequency discharge techniques. These colors were identified as predominantly CO_2 molecular emissions, and other colors, such as yellow, appeared as the density of NO_2 increased. Silberg (1962, 1965) discussed the formation of green-colored ball-like clouds formed during large direct current discharges. The green color was attributed to copper vapor from the electrodes. Refer to Chapter 7 for more detail on these and other experimental results.

Structure. In general, there are three structural types. First, a solid appearance with a dull or reflecting surface or a solid core within a translucent envelope; second, a rotating structure, suggestive of internal motion and stress; and third, a structure with a burning appearance. All three structures are observed with each shape but not with equal frequency. The burning structure has been reported most often with the spherical and oval shapes, a red or red-yellow color, and a diameter less than 40 cm. Ball lightning reported to have a solid structure commonly has a green or violet color and a diameter between 30 and 50 cm. The rotating structure is observed with a combination of colors. It usually has a bright-colored interior with darker-colored poles or a translucent envelope.

Motion. The single most distinctive property of ball lightning is motion. Categorizing the motion by path, we have (a) cloud to cloud; (b) earth or near earth to cloud; (c) cloud to earth, or near to earth; (d) horizontal path near and above the earth; (e) spiral or random path above the earth; and (f) motionless, stationary above the earth. In general, ball lightning is most commonly observed in descending motion, apparently from a cloud. It usually assumes either a random or horizontal motion several meters above the ground. The motionless state often results after an initial random or horizontal motion, although it can occur sooner. The first two types of motion listed above are reported least—only a few of over 1600 reports indicate such motion. Kuhn (1951) and Tripe (1888) are two examples of reports on the rising type of ball lightning.

Ball lightning has no predominant color–motion relation. However, those with horizontal paths are usually of the burning structure, yellow or red in color, and spherically shaped with a diameter less than 40 cm. The random path type are yellow, red, or white in color with solid structures, and have oval or spherical shapes with diameters of less than 30 cm.

The motionless ball lightning is observed to hover in midair, seemingly unaffected by external forces. It is usually red or yellow-white in color, spherical or oval shaped with a diameter of about 30 cm. It is often observed to undergo a sudden attraction to a grounded object. It darts quickly to the grounded object and decays noisily upon contact.

Several review papers have indicated that ball lightning can move against the wind but furnish no references to support this property. In the survey by Barry (1967a) only three reports describing this property were found. G. H. Brown (1957) reports a ball lightning that maintained a motionless state in a windy region; Browne (1964) reported on a ball lightning event in 1665 which moved slowly against a gentle breeze; and Anon (1887h) reported a similar event at sea. The data accumulated indicate that if a wind-related motion is mentioned in a report, the ball lightning is most often observed to move along with the wind rather than against it.

Sound. A characteristic hissing sound is often associated with the presence of ball lightning by many review authors. Only a few first-person reports, such as Dmitriev (1967a,b), were found which specifically mentioned a sound characteristic in connection with a nearby ball lightning observation. Conversely, a hissing sound is definitely associated with the St. Elmo's Fire phenomenon which is occasionally misidentified as ball lightning. Consequently, we may conclude that ball lightning is predominantly a soundless phenomenon.

Odor. Many observers report a distinctive odor accompanying the presence of ball lightning. The odor is described as sharp and repugnant, resembling ozone, burning sulfur, or nitric oxide. As might be well understood, an odor is reported most often when the distance between the ball lightning and the observer is small. The reported odor characteristic has been used by Thornton (1911d) as the basis for a ball lightning model. It is now considered somewhat extreme to base a model on such a characteristic. To do so would imply that an untrained observer can identify and distinguish between the odors of ozone, burning sulfur, nitric oxide, or some other similar odor. Odors of this type are common ionization products of a lightning discharge, as found, for example, by Reynolds (1923).

Damage and Heat. Since the ball lightning is apparently an atmospheric electrical phenomenon, the emission of heat would be expected. A small number of observers do report that heat emission was experienced during the event. Stenhoff (1976) discussed a ball lightning that came in contact with the observer and caused burns on her hand and damage to her clothing. Owen (1886) reported an observer burned when the ball lightning touched her foot, and Anon (1890e,n) reported a man burned and rendered unconscious. Babick (1955) also reported heat felt by the observer. Minchin (1895) discussed a boy injured by the phenonenon, and Wainhouse and Pitcairn (1773) report a man burned on the shoulder by a ball lightning. Other reports of injury to observers by the ball lightning heat emisson include E. Hill (1897), Israel (1950), Lindemann (1951), McMillan (1889), Palmer (1752), and Ryan (1895),

The possibility of extreme bodily harm is occasionally discussed with regard to the ball lightning event. Deaths attributed to ball lightning have also been reported. The death of Dr. G. W. Richmann in Petersburg in 1752 has become a famous example of the dangers of ball lightning. Dr. Richmann's fate has been discussed in numerous reports. Examples are those of Figuier (1870, 1884), Flammarion (1874), Mendenhall (1890), Powell and Finkelstein (1970), Schuster (1896), and the initial report by Watson (1754). See Chapter 7, Section 7.2.

Dr. Richmann was a noted scientist of his time who was performing experiments during thunderstorms using an apparatus to attract lightning to his laboratory. It was reported that a ball lightning appeared within his laboratory subsequent to a lightning strike to his equipment. The ball lightning was reported to have moved through the air, hitting Dr. Richmann on the head and causing his death. The event has been recorded in a drawing which has been reproduced by Figuier (1870, 1884) and Powell and Finkelstein (1969, 1970). Anon (1886b) reported a man killed by a ball lightning event. Dolbear (1887), Minchin (1895a), Roth (1889) and Anon (1890e) also reported animals killed by a ball lightning.

Damage to objects that were touched by a ball lightning has also been reported. Carruthers (1947) reported damage to a tree after a ball lightning bounced from a set of wires. Covington (1970) reported that a piling was split by a ball lightning, causing considerable damage to a wharf. Both Pcholko (1963) and Wojskowy (1966) reported airplanes hit and damaged by collisions with ball lightning. Lodge (1892) reported that a ball lightning hit the ground near a lake and created a hole about 2 to 7 in. (5 to 18 cm) in diameter and 4 ft (1.2 m) deep.

In contrast to these reports of serious damage, others have indicated that ball lightning does not emit heat and does not cause harm to

objects. Margs (1956) reported that no heat was detected by a close observer, but that the fireball damaged a roof. In contrast, Muirhead (1883) observed a ball lightning on a roof which caused no damage. Browne (1964), analyzing a ball lightning event in 1665, indicated that no heat was felt and no damage found after the object struck a house. Foster (1947) reported that a ball lightning hit a pole but caused no damage.

It would appear that there is some contradiction among the various reports. The cause of the contradictions is unknown but some investigators have speculated that several forms of ball lightning exist. Since many of the reports indicate damage or injury by a ball lightning, it would be wise to avoid such encounters.

Lifetime. The lifetime of a ball lightning is most often reported to be only 1–2 sec. A lifetime of this length or less was reported or indicated in about 80% of the reports examined. In about 40% of these cases, the lifetime was deduced from data reported by the observer. For instance, one observer reported seeing a ball lightning move through a window into a room, slowly cross to the other side, and violently disappear. The speed of ball lightning was estimted by the observer at about the speed of a person's walk. Assuming the distance traversed by the ball lightning to be about 7 m and its speed to be 2 m sec^{-1} (a normal walking speed), a lifetime of a few seconds is deduced. A small percentage of reports indicated longer lifetimes, lasting up to minutes. The longer lifetime is highly correlated with the motionless blue or blue-white ball which is considered to be St. Elmo's Fire.

Decay. Ball lightning has been observed to decay by two modes. One is the silent decay, associated with a decrease in brightness and diameter. The second, designated as the explosive mode, is associated with a loud violent sound. Some observers report a sudden color change preceding the explosive decay. Others report an explosive decay mode and also report a lack of damage to the surroundings even though the explosive decay occurred near some breakable object. This may suggest an implosive decay rather than explosive decay.

A small percentage of observers mention a residue found after the decay. Winchester (1929) reported a smoke or fog residue. A tar or soot residue found at the point of contact of a ball lightning or dropped during its passage has been reported by Anon (1887c), Davidov (1958), Kogan-Beletskii (1957), and Webber (1907). The rarity of residue reports is probably due to the lack of critical examination of the environment where an event occurred.

Lightning Dependence. The occurrence of ball lightning is commonly associated with natural lightning events during thunderstorms, torna-

does, earthquakes, and other such stressful conditions in nature. These observations are the basis for the assumption that ball lightning is associated with the ordinary lightning discharge and is an electrical phenomenon. This association is supported by reports that describe a ball lightning appearing simultaneously with a nearby ordinary lightning discharge, immediately following the stroke, or just preceding the discharge. About 90% of the ball lightning observations reported occurred during thunderstorm activity. These percentages are supported by similar numbers derivable from other surveys, such as those by Arago (1854), De Jans (1910), Brand (1923), and Sauter (1895).

Ball lightning has also been reported to have occurred during many stresses of nature other than thunderstorms. Ball lightning at sea during stormy weather has been reported but without other lightning being present. Such reports have been made by L. E. Chalmers (1751), Marsh (1895, 1896a,c), Moon (1925), and Swart (1888). Luminous phenomena as well as ball lightning reports have been observed during earthquakes and snow storms as well. The appearance of a ball lightning during a snow storm was reported, for example, by Zalesskii (1958). A 4-cm-diameter red-colored sphere was observed to form about 4 m above the ground. Electrical activity was apparent as small-scale discharge crackling between the electrified snow flakes was audible.

Electrical activity in falling snow has been previously studied. Herman (1964), for example, found that the space charge in blowing snow could be 5×10^{-10} C m^{-3} or a charge per snow particle of order 1×10^{-15} C. That would be 10^2–10^3 greater than that for falling or squall snow. Since the electron charge is 1.6×10^{-19}C, falling snow may have a charge per particle of about 10–100 electrons.

Latham (1964) made an analysis of the electrical properties of natural and artificial snowstorms and sandstorms. The charging of snowflakes and sand particles results from the asymmetric rubbing of one flake or particle with others. Charge transfer results because of the preferential migration of ions of one sign from a relatively hotter region to a relatively colder region. In the case of snow, the concentration of H^+ and OH^- ions on ice is very dependent upon temperature, increasing with increasing temperature. The mobility of the H^+ ion is greater than that of the OH^- ion at all practical temperatures. The more rapid diffusion of H^+ ions will lead to a net charge gradient which follows the temperature gradient in the snowstorm region.

A study by Anderson et al. (1965) of volcanic smoke and gas ionization showed that large electric fields, not unlike those found with thunderstorms, exist within the volcano cloud. Freier (1960) found that strong electric fields result from the frictional action of dust particles in motion with one another. Funder (1939) reported that strong electric

fields and large ion densities exist in fire damps. Thus, strong electric fields appear to be common to the natural disturbances in which a ball lightning might occur. Consequently, the formation of ball lightning would appear to be dependent upon the presence of charged air particles and electric fields rather than a normal lightning discharge. This is not really in conflict with those reports of ball lightning having been formed immediately after a lightning discharge, for example, Hohr (1903). The electric field dependence is related to both phenomena.

In an investigation of earthquake records dating back to 860 A.D., Terada (1931) and Musya (1931) found that luminous earthquake phenomena included many common lightning forms and atmospheric luminous phenomena, such as ball lightning. The earthquake ball lightning exhibited the same general properties as thunderstorm ball lightning.

Luminous phenomena and ball lightning sightings are frequently reported during wind storms. Audoin (1913), Cadenat (1908), Dauvillier (1965), Dessens (1965), Faye (1890), Flammarion (1874), Scott (1878b), Vaughan and Vonnegut (1974), and Vonnegut and Meyer (1965) reported such events during tornadoes and gales.

The effects of ball lightning and other luminous phenomena have been discussed by Botley (19669 and Vonnegut (1960), who also refer to earlier repots of such tornado activity. Vonnegut (1960) and Vonnegut, Moore, and Harris (1960) considered the physics of the electrical activity accompanying tornadoes and proposed that thunderstorm and electrical activity may in fact lead to tornado formation. It was later found by Watkins, Cobine, and Vonnegut (1978) with vortex-stabilized arc experiments that the electrical activity has insufficient power contribution to the total tornado power to be a significant power source.

Vonnegut and Weyer (1965) and Vaughan and Vonnegut (1974) have obtained photographs of luminous phenomena that appeared with tornadoes. A number of luminous forms were reported: large areas covering a portion of the sky, pillars and columns, and ball-lightning-like objects. These photographs and descriptions verify that such objects may be formed without apparent large-scale thunderstorm electrical activity.

A direct relationship between the occurrence of natural lightning and the formation of ball lightning has been assumed by many investigators. The average rate of worldwide lightning events has been estimated with satellite optical detectors by Turman, Edgar, and Friesen (1978) as about 1×10^{-6} km^{-2} min^{-1}. The general areas of most frequent lightning events were reported to be Southeast USA, Gulf of Mexico, Central America, Central Africa, Southeast Asia, India, and Southern China. These results are significant in that the areas of most

frequent ball lightning reports, as indicated by the publication sources of the 1100 reports on ball lightning indicated in Figure 1.3, which are generally Central and Western Europe, are not the geographical zones of greatest lightning activity. It is believed that this finding may be a result of the circumstances and events at the time of the original observation, such as the availability of an acceptable reporting medium or some peculiarity related to the formation of ball lightning. It may also indicate that natural lightning is not required for the formation of ball lightning.

Attraction to Enclosures. Approximately 10% of the observers report an affinity of ball lightning for enclosures. Holmes (1934a,b), for instance, reports the sudden appearance of a ball lightning within a room. Others, such as, Malsch (1956) and Subramaniam (1962), have observed a ball lightning to enter a room by way of a chimney or through a partially open window or door. In general, once inside a room, a ball lightning often decreases its speed to a slow circular motion. Some observers report that a ball lightning possesses a motionless, hovering state within a room, while others report that the ball lightning moves in random patterns. Most of the reported observations within a room agree in one characteristic. The enclosed ball lightning decays by the explosive mode, usually with a lack of damage to the room or its contents.

This type of occurrence is commonly discussed as a characteristic of a ball lightning event. However, it is not frequently reported by first-person observers. A number of such reports have been accumulated and are listed in Table 3.1.

Altitude of Observations. Ball lightning is predominantly observed at

Table 3.1 References to Observations of Ball Lightning within Enclosed Spaces

Adamson (1890)	Holmes (1934a,b)
Anon (1886b)	Kaiser (1924)
Anon (1891k)	Marchant (1930)
Anon (1913)	Margs (1956)
Anon (1914b)	McMillan (1889)
Anon (1934)	Mohn (1908)
Bay (1908a–c)	Nippoldt (1916)
Brew (1893)	Richter (1913)
Brzak (1892)	Ryan (1895)
Cabellero (1890i)	Subramaniam (1962)
Cocking (1884)	P. G. Tait (1884)
Donough (1887)	Wainhouse and Pitcairn (1773)
Dolbear (1887)	Weber (1911)
Herrich (1954)	Weber (1915)
Hohn (1966)	

Table 3.2. References to Observations of Ball Lightning within or near Aircraft

Anon (1964b)	Kogan-Beletskii (1957)
Baratoux (1952)	Lilienfield (1970)
Felsher (1970)	Newman (1960)
Gold (1952)	Pcholko (1966)
Goodlet (1937)	Teich (1955)
Jennison (1969)	Uman (1968a)
Jennison (1971)	

low altitudes. This does not imply that ball lightning cannot occur at high altitudes, but rather that, since an observation is obviously dependent upon the presence of an observer, most observations will occur at low altitudes. Approximately 99% of ball lightning observations have been initially made near the ground.

It should be noted that the altitude of observation does not necessarily mean that the ball lightning was formed there. Bauman (1937) and Eriksson (1977a) have suggested, based upon some photographic evidence (which is admittedly not definitive), that ball lightning may be formed by lightning strokes hundreds of meters above the ground. Some observation reports also indicate a ball lightning falling from a cloud.

A number of high-altitude observations have been reported while the observer was within an aircraft. The characteristics of the phenomenon described in those reports do not differ from those described in reports of observations made at ground level. The ball lightning phenomenon has been observed outside of the aircraft as well as within the aircraft. Jennison (1969, 1971) and Uman (1968a), for example, discuss the occurrence of events observed within aircraft. Kogan-Beletskii (1957), Pcholko (1966), and Wojskowy (1966) report contact and possible damage to aircraft.

Since such observations are of particular interest because of their very uncommon occurrence, a number of such references have been listed in Table 3.2. These references are of particular interest to those interested in proposing theories for the formation and continued existence of ball lightning. A major aspect of many theories has been the energy source for the event. The question is, is it external or internal? Since ball lightning has been observed to come into contact with conductors without being immediately terminated, the suggestion of external sources providing the energy has been questioned. The fact that ball lightning has been observed within metal enclosures is a more serious problem, since the existence of ball lightning within a metal enclosure is not compatible with an external energy source.

4

Deduced Characteristics of Ball Lightning

The reported characteristics of ball lightning may be used to deduce other characteristics of the phenomenon that are not so readily apparent. We must assume, however, that the observed properties are valid and reliable as reported. We will also assume that basic physics is applicable to the data available.

4.1. Mass Density

Most ball lightning reports appear to agree in one characteristic—that is, the ball lightning either hovers in the air, apparently motionless or with only gentle random motion, or it descends as if from a higher altitude. These factors, coupled with the reports that very few have been observed to rise, may be indicative of a density property.

A descending motion would suggest a mass density larger than that of air, ascending would suggest a mass density less than that of air, and no apparent upward or downward motion would suggest a mass density equivalent to that of air. This means that the mass per unit volume (g cm^{-3}) of ball lightning is approximately that of air, that is, about 1.29×10^{-3} g cm^{-3}.

That the mass density of ball lightning must be about that of air does not specify its exact molecular composition. A small impurity would have negligible effect on the total mass. The *American Institute of Physics Handbook* by Gray (1957) indicates that the mole fractional composition of dry air is 78.05% N_2, 20.95% O_2, 0.93% Ar, 0.03% CO_2, with traces of Ne, He, Kr, H_2, Xe, O_3, and Rn. Moist air would also contain H_2O vapor. That small amounts of impurities can have signif-

icant effects on the emission characteristics will be discussed in Chapter 7. Consequently, we assume that the mass density of ball lightning is similar to that of air but make no assumption regarding minor constituents that may be present. It should be recognized that small mass density asymmetries have not been considered.

The density of a ball lightning being approximately that of air contradicts the concept that ball lightning is a fully ionized plasma and that its temperature is extremely high. A high temperature is defined as greater than 10^4°K. A very hot gas would be expected to expand rapidly and diffuse into the surrounding air. However, that a partially ionized gas might be maintained will be considered later in this chapter.

4.2. *Energy Density*

The energy content and energy density of the ball lightning phenomenon is of considerable interest to those investigating its properties and origin. The energy content of ball lightning is also needed in order to analyze the phenomenon theoretically and to speculate about a mechanism for its formation and continued existence. Any model for ball lightning must provide for an energy source capable of sustaining the characteristics observed for the phenomenon.

The energy content of ball lightning has been deduced a number of times in the past for a small number of events where sufficient data existed for analysis. It must be noted that a uniform energy distribution had been assumed in all calculations available to this author. However, realistic consideration of that assumption leads us to conclude that nature may not be so simple. We would expect that the energy density profile would be spherically symmetric and could vary along a radial vector from the ball center, decreasing at some rate and becoming equal to that of air at the outer regions of the ball. This consideration avoids the physical problem of a sharp discontinuity of energy density at the surface and is more satisfying to our understanding of natural phenomena. This assumption does not preclude the possibility of the energy density changing rapidly over a thin layer at the ball boundary—a skin effect.

In terms of the energy density, the total energy of a ball lightning should be given by

$$E_0 = \int_{r=0}^{r=R} f(r) 4\pi r^2 dr \qquad (4.1)$$

where $f(r)$ is the radial distribution of the energy density, r is the radial distance, and R is the boundary distance. A uniform energy distribution would have $f(r)$ = constant and the total energy E_0 would be a simple relation, $E_0 = f(r) \times V$, where V is the ball volume. A nonuniform energy distribution—for example, a Gaussian with $f(r) = \epsilon_0 \exp(-2r^2/a^2)$, where a is the radial distance at which the energy density falls to $1/e^2$ of its value at $r = 0$—could give rise to an equivalent or totally different value for the total energy.

It must be recognized that almost any energy distribution may be assumed with equal validity, or perhaps with equal uncertainty. We have no definitive data that provide information concerning the correct energy profile for a ball lightning. We can make physically acceptable arguments to establish limits: For example, we could argue that the energy density of the ball is constant at its core aad decreases in some fashion near the boundary to become equivalent to that of air. We assume from the observations that the core temperature, or the equivalent energy density, is not too different from that of the outer areas. If this were not correct, the ball color and structure would appear nonuniform, somewhat contrary to reported observations.

A few observers, however, have reported that the ball lightning appeared to have structure. Baratoux (1952), for example, gave a detailed description that included several zones of apparently different density. An internal motion was suggested by the observation of Dmitriev (1967a) and a radial variation by Dmitriev, Deryugin, and Kalinkevich (1972).

Since there is a need to define an energy density for comparative, modeling, and theoretical purposes, the uniform energy distribution has been assumed. The energy distribution is therefore defined by the relation

$$\mathscr{E}_{BL} = E_0/V \tag{4.2}$$

where E_0 is the total energy of the phenomenon deduced from the observational evidence and V is the ball volume, usually calculated from the reported (optical) diameter. A number of ball lightning events, descriptions, and evaluations are provided herein and the results interpreted relative to the possible form(s) of ball lightning. The events are discussed in the following cases.

Case 1. A rather famous incident which enabled an energy for a ball lightning to be calculated was that reported by Morris (1936) and discussed by Goodlet (1937). A red ball lightning about the size of an orange was observed to descend from the sky, strike a house, cut a

telephone wire, burn a window frame, and then come to rest in a barrel filled with about four gallons of water. The water was reported to have boiled, remaining too warm to touch even 20 minutes later, indicating a substantial release of heat. No residue was found upon inspection of the water after it had cooled. The minimum energy of the ball lightning can be deduced by making a few basic calculations. Ignoring the broken wire and burned window frame, we concentrate on the heat supplied to the water in the barrel.

We assume that the initial water temperature was 20°C and the final water temperature was about 60°C. The amount of water was reported as about four gallons (18 liters, assuming British units). Morris (1936) did not specifically indicate any amount of water loss due to boiling. One calorie (4.19 J = 1 cal) of heat must be added to 1 cm^3 of water to increase its temperature by 1°C. Therefore, the heat introduced into the water must have been at least 3×10^6 J.

A ball diameter equivalent to that of a large orange, here assumed equal to 10 cm (4 in.), was mentioned by C. V. Boys in the discussions following the Goodlet (1937) paper, so that

$$\mathscr{E}_{BL}(\text{case 1}) \simeq 5.7 \times 10^3 \text{ J cm}^{-3} \tag{4.3}$$

This value is slightly less than that which would result had loss of water through evaporation been included. The evaporation of water requires another 538.7 cal (2257.1 J) cm^{-3}.

Since the report by Morris (1936) is one of the few that allows the energy of a ball lightning to be deduced, several other calculations have been made. Goodlet (1937) calculated an energy value of 3.8×10^6 J based upon the assumption of no water evaporation, an intial temperature of 10°C, and a final temperature of 60°C. He also calculated an energy value of 1×10^7 J based upon the assumption that 4 lb (1 lb $\cong$ 454 cm^3) of water were evaporated. The related energy density values, assuming a 10-cm- (4-in.) diameter ball lightning, and using equation (4.2), would be

$$\mathscr{E}_{BL}(\text{no loss, Goodlet}) \simeq 7.3 \times 10^3 \text{J cm}^{-3} \tag{4.4}$$

and

$$\mathscr{E}_{BL}(\text{loss, Goodlet}) \simeq 1.9 \times 10^4 \text{ J cm}^{-3} \tag{4.5}$$

Several other authors have considered the Morris (1936) and Goodlet (1937) discussions. Carpenter (1963) deduced an energy density value of

$$\mathscr{E}_{BL}(\text{case 1, Carpenter}) \simeq 2.5 \times 10^3 \text{ J cm}^{-3} \tag{4.6}$$

and F. L. Hill (1960) calculated an energy density value of

$$\mathscr{E}_{BL}(\text{case 1, Hill}) \simeq 2.4 \times 10^3 \text{ J cm}^{-3} \tag{4.7}$$

Altschuler, House, and Hildner (1970) also commented on the Goodlet (1937) discussions, as well as on reports by Chalmers (1751) and Marcet (1888), and estimated that the energy density of ball lightning could be as large as

$$\mathscr{E}_{BL}(\text{case 1, AHH}) \simeq 4 \times 10^3 \text{ J cm}^{-3} \tag{4.8}$$

Barry (1967) also discussed the event and calculated an energy density value of

$$\mathscr{E}_{BL}(\text{case 1, Barry}) \simeq 2.5 \times 10^3 \text{ J cm}^{-3} \tag{4.9}$$

based upon a 15-cm diameter ball.

It should be clear that different values have resulted, primarily due to the differences in assumptions. It is clear, however, that an energy density of at least 2×10^3 J cm^{-3} may have been possessed by the ball lightning phenomenon.

Case 2. A second reported event allows us to calculate another ball lightning energy density in a similar manner. Covington (1970) and Zimmerman (1970) discussed a ball lightning which descended into a wharf piling, resulting in its being shattered into splinters.

It is assumed that the log was shattered as a result of the heating of water within its body causing rapid expansion and splitting of the wood. In order for wood to be splintered in this manner, the tensile strength of the wood perpendicular to the grain must be exceeded by an outward radial pressure. Here the pressure is assumed to have been caused by water vaporized within the wood by the hot ball lightning.

The tensile strength (S) of wood depends upon the type, age, growth characteristics, and other factors. Let us use a value of $S = 500$ atm (1 atm = 14.7 lb/in.^{2} = 0.98 kg cm^{-2}), which is comparable to that for an oak log. In order to create an outward radial pressure, we assume that it would be necessary to vaporize a circular sheet of water to steam. The evaporation develops a pressure greater than the value S as the steam is constrained by the limited volume that the water has occupied.

The conversion of a volume of water V_w to steam is easily greater than the value S. At normal temperature and pressure 18 g of water are converted to one mole of steam (1 mole = 22.4 liter = 2.24×10^4 cm^3) and the pressure P is defined by the gas law

$$PV = nRT \tag{4.10}$$

where V is the volume, R is the universal gas constant, $R = 82.06$ when V is measured in cm^3, n is the number of moles involved, and T is the temperature in °K.

$V_w/18$ moles of steam are produced from $V_w\ \rho$ grams of water: ρ is the density of water, $\rho = 1\ g\ cm^{-3}$. According to the gas law, the pressure produced by water converted to steam at $T = 100°C$ (373°K) is given by

$$P = (V_w/18)R(373)/V_w \tag{4.11}$$

which is $P = 1700$ atm.

We assume that within the log a small cylindrical sheet section of water exists at radius r_1 and has a thickness Δr. The volume of water is then

$$V_w = 2\pi r_1 \Delta r L \tag{4.12}$$

In order to provide an estimate of the ball lightning energy density, we must make assumptions regarding the cylindrical sheet of water in the log. We assume that the radius of the cylindrical sheet $r_1 \cong 7.5$ cm, the thickness is small, $\Delta r \cong 0.1$ mm (0.037 in.), and the log length $L \cong 121.9$cm (4 ft). The volume of water is then

$$V_w = 57.4\ cm^3 \tag{4.13}$$

In order to increase the temperature of water by 1°C, 1 cal cm^{-3} must be added. In order to convert 1 cm^3 of water at 100°C to steam at 100°C, 538.7 cal cm^{-3} must be added. The heat necessary to convert 57.4 cm^3 of water at 20°C to steam at 100°C is then

$$E \simeq 0.15 \times 10^6 J \tag{4.14}$$

and the energy density, assuming a uniform energy distribution and a ball radius of 7.5 cm, would be

$$\mathscr{E}_{BL}(\text{case 2}) \simeq 85\ J\ cm^{-3} \tag{4.15}$$

It is understood that the energy density might vary if the radial profile of the density and energy distribution were known.

Case 3. A ball lightning event in which an observer was struck and burned provides the basis for another energy calculation. Stenhoff (1976) and Wooding (1976) discussed a fireball which was observed to suddenly appear within a room. The ball had a halo around an apparent central core with an overall diameter of about 10 cm (4 in.) and lasted

for about 1 sec. The ball struck the observer's clothing and brushed against her hand. The contact burned a hole in the fiber, melted a larger area of the polyester material, and burned her ring finger by heating her gold ring. If the irregular burned area in the clothing as illlustrated by Stenhoff (1976) may be considered to be indicative of the ball dimensions, then its core must have been about 20 mm in diameter.

The polyester material used in the clothing melts at about 250°C and has a specific heat capacity (H) of 1.2 J $g^{-1}°C^{-1}$ and a density (ρ) of about 1 g cm^{-3}. The size of the hole was about 100 × 70 mm and the cloth was about 0.1 mm thick. The heat required to melt the material and create the hole would be

$$E_1 = H\Delta T\rho V \tag{4.16}$$

where ΔT is the temperature change, say, from 20°C to 250°C, and $V = 10.0 \times 7.0 \times 0.01 = 0.7$ cm^3, so that

$$E_1 = 193\text{ J} \tag{4.17}$$

The observer also reported that the light from the glowing ball illuminated her body. Let us assume that the ball radiation was equivalent to that from a 50-W light bulb, so that during the 1-sec ball life

$$E_2 = 50\text{ J} \tag{4.18}$$

The burn on the observer's ring finger also permits another heat calculation. The burn was described as less than a scald so it may be assumed that the skin temperature was below 100°C. The heat required to cause the rise in temperature of the gold ring may be calculated in the manner of equation (4.16). The specific heat capacity (H_1) of gold is about 0.126 J $g^{-1}°C^{-1}$, the density (ρ) of gold is about 19.3 g cm^{-3}, and a normal ring has a volume of about 1 cm^3. The heat input is then given by

$$E_3 = H_1\rho V\Delta T \tag{4.19}$$

where a ΔT of 80°C is assumed, so that

$$E_3 = 194\text{ J} \tag{4.20}$$

Adding the various estimates of heat deposited as calculated above, $E = E_1 + E_2 + E_3$,

$$E = 440\text{ J} \tag{4.21}$$

and using equation (4.2), the uniform energy density for a 20-mm-diameter ball lightning would be

$$\mathscr{E}_{BL}(\text{case 3}) = 105\ \text{J cm}^{-3} \tag{4.22}$$

It is important to recognize that the calculation of the value above differs in one possible significant respect from the other calculations. The ball lightning was observed to have an (optical) diameter of 10 cm (4 in.), but based upon physical evidence, it apparently had a real diameter of about 2 cm (0.75 in.). The true diameter was deduced from the physical evidence of the ball contact.

If we calculate the energy density based upon the observed (optical) diameter, which is consistent with the other calculations, we find that for a 10-cm- (4-in.-) diameter ball lightning

$$\mathscr{E}^{*}_{BL}(\text{case 3}) \simeq 0.8\ \text{J cm}^{-3} \tag{4.23}$$

which is essentially 1% of the supposedly true energy density, but calculated in a manner consistent with other observations and reports.

Case 4. The energy of a ball lightning was estimated by Dmitriev (1967a, 1969) based upon experimental data that were related to the observation. An illuminated, slightly ellipsoidal object was originally reported to have appeared over a body of water after a natural lightning stroke. The object appeared to have a brilliant white core surrounded by two luminous shells, the inner one violet in color and the outer blue in color. The major axis diameter was about 14 cm. The ball lightning lasted about 80 sec and disappeared upon contact with an object in the area.

It appeared to Dmitriev that energy was continuously generated in the ball as electric crackling and light were continuously emitted. A visible blue mist trail was left behind as the ball moved with the wind. Gas samples were taken in the vicinity of the ball. Mass spectrometer analysis was used to determine the gas species and concentrations.

It was found that the concentrations of ozone and nitrogen oxides, which were assumed to be NO_2, were much higher than in normal air. The values cannot be used to form a strictly valid model, as such gases are also formed during normal lightning discharges. However, it was found that the hydrogen-to-oxygen concentration ratio was about 4×10^{-6}. If the ball lightning had been the result of some detonating or burning gas, the ratio should have been about 3×10^{-3}.

The concentration of NO_2 was measured to have been from 92.3 μg m^{-3} to 1645 μg m^{-3} in four tests. It was assumed that the measured concentration of NO_2 could be related to the electrical energy deposited in an air volume. Laboratory experimentation with electrical discharges in air has shown that the NO_2 concentration is related to the energy

input by

$$[NO_2] = 6.8E \tag{4.24}$$

where $[NO_2]$ is in $\mu g\ m^{-3}$ and E is in $J\ m^{-3}$. The concentrations of 92.3 and 1645 $\mu g\ m^{-3}$ correspond to 13.6 and 240 $J\ m^{-3}$. The total molecular concentration was taken to be $5.3 \times 10^{17}\ cm^{-3}$ and a mean ionization energy of 14.5 eV was assumed. The total energy storage was estimated as 530 J. The corresponding energy density for a 14-cm-diameter ball, following equation (4.2), would have been

$$\mathscr{E}_{BL}(\text{case 4}) = 0.37\ J\ cm^{-3} \tag{4.25}$$

Chameides, Stedman, Dickerson, Rusch, and Cicerone (1977) measured the production rate of NO_x molecules (NO, NO_2, NO_3, N_2O_5, HNO_2, HNO_3) during lightning discharges as about 6×10^{16} molecules per joule of electrical dissipation. The presence of water vapor had no detectable effect. The average energy expended by a lightning flash with a channel diameter of 1–10 cm is about $10^5\ J\ m^{-1}$. The related NO_x density due to normal lightning is then from 7.6×10^{15} to 7.6×10^{17} molecules cm^{-3}. This value is essentially the same as that measured by Dmitriev (1969) and suggests that the object observed was similar to normal lightning in its capability of producing NO_x molecules in air.

Case 5. Wittmann (1971) reported the observation of a ball lightning event during a thunderstorm accompanied by heavy rain near Coburg, Germany. A spherical, brightly luminous yellow ball was observed to appear about 24 m from the observer at a height of about 16 m above the ground. The diameter of the ball was 50–100 cm and descended with a speed of about 4 m sec^{-1}. Its flight ended at the top of a nearby tree. It was observed to disintegrate into 8–12 smaller spheres which were of the same yellow color with a diameter of 12–15 cm. The small spheres fell to the ground and disappeared silently upon contact with the ground. No lightning flash accompanied the appearance of the initial sphere so retina afterimage was discounted. The phenomena were observed again a few minutes later, the second occurrence identical to the first. This observation may be recognized to be opposite to that witnessed by M. Scott (1878b). Scott reported that many small green luminous spheres on a tree rose upwards to form a larger sphere, which then floated free.

Some of the small luminous spheres reported by Wittmann fell to the asphalt roadway under the tree. The area was inspected and circular patches of melted asphalt were noted. The diameter of the melted areas

was 12–15 cm and the areas were assumed to be the impact point of the small luminous spheres. Wittmann (1971) reported that several witnesses observed the incident and described the event in a similar manner.

Wittmann calculated the energy density of the small spheres based upon the roadway evidence. Asphalt contains B-80 bitumen, a thermoplast which has liquid components that disintegrate at about 170°C. It was assumed that a water layer of 0.5 mm thickness at 20°C was originally heated and evaporated by the luminous ball. Additionally, a 1-mm-thick layer of asphalt was assumed heated to 170°C. The parameters assumed for the B-80 bitumen were a density (ρ) of 1 g cm^{-3} and a specific heat capacity (H) of = 1.9 J g^{-1}°C^{-1}. The energy to melt the B-80 bitumen is then determined from

$$E = H\rho V\Delta T \tag{4.26}$$

and has a value, for a 12-cm-diameter ball lightning, of

$$E_1 \cong 3.4 \times 10^3 \text{ J} \tag{4.27}$$

The energy needed for water evaporation, with 1 cal cm^{-3} required to warm water 1°C, and 538.7 cal cm^{-3} required to convert 100°C water to steam at 100°C, has a value of

$$E_2 = \cong 1.6 \times 10^4 \text{ J} \tag{4.28}$$

The total energy is the sum $E = E_1 + E_2$,

$$E \cong 1.9 \times 10^4 \text{ J} \tag{4.29}$$

and the energy density, following equation (4.2), for a diameter of 12 cm, is given as

$$\mathscr{E}_{BL}(\text{case } 5) \simeq 21 \text{ J cm}^{-3} \tag{4.30}$$

The value of $\mathscr{E}_{BL}$ is of course dependent upon the amount of B-80 matter affected. The melting may have occurred to greater than the 1 mm depth, and the B-80 temperature may not have reached 170°C to cause local deformation. The actual thermal transfer is unknown. It is quite reasonable that the value calculated should be a lower bound.

Wittmann also reported that these observations were quite different from another made years later. During a thunderstorm with a heavy rainfall, a normal discharge was observed to occur to a building roof. An intense point discharge occurred at the point of contact immediately following the lightning stroke. The point discharge lasted 1–2 sec but was not considered as a ball lightning event. The point discharge may have been similar to those photographed by Hubert (1975a), Fieux,

Gary, and Hubert (1975), and Fieux and Hubert (1976). The luminous phenomenon was speculated by Hubert to have resulted from gases released at the point of the discharge and excited thermally to produce visible radiation.

Case 6. Even though a ball lightning was not directly observed during a thunderstorm, witnesses did report a persistent glow near a house. The glow remained for 2–3 sec after a lightning flash. A power failure occurred immediately after the glow disappeared.

The area was examined and a crooked trail of scorched grass led from a tree to a metal rain spout at a nearby house. The tree was not noticeably damaged or burned. The path was about 10 m in length and had a visible width of 10 cm. At the end of the path near the waterspout was a light bulb under the house eaves. The bulb had a quarter-inch hole which appeared to have been caused by a hot object. It was reasoned that the flow had originated from an atmospheric electrical phenomenon which had scorched the grass and terminated at the bulb. The phenomenon may well have been a normal lightning stroke that was not observed and the illumination from which lasted longer than normal. It may be speculated that a ball lightning was formed and caused the observed glow and burned the trail in the grass.

In order to estimate the energy required to burn the grass, a coil heater was operated by Anderson and Freir (1972) at different power levels for various periods of time at several points on the lawn. The heater was calibrated by a calorimetric method. A best match between the intentionally caused grass burns and those of the lightning event was found when the heater was operated at about 30 W power (P) radiated to the grass for 300 sec (t) at a height of 10 cm over the grass and causing a burn spot about 10 cm in length.

The energy intentionally transferred to the grass over the 10-cm test path was then about

$$E_{\text{test}} \simeq 9 \times 10^3 \text{ J} \tag{4.31}$$

The total energy radiated to the grass must be greater than the value above by the ratio of the total path length to the test path, 10 m to 10 cm, or

$$E_{\text{total}} \simeq 9 \times 10^5 \text{ J} \tag{4.32}$$

The ball diameter was estimated to have been 4 in. (10 cm) from examination of the scorched path. The corresponding energy density calculated by Anderson and Freier (1972) was

$$\mathscr{E}_{\text{BL}}(\text{case } 6) \simeq 1.7 \times 10^3 \text{ J cm}^{-3} \tag{4.33}$$

Higher values could also be calculated if spherically uniform heat emission is assumed. A 10-cm-diameter ball situated 10 cm above the grass could have an energy density of 1×10^4 J cm^{-3}. Anderson and Freier (1972) also recognized that the calculated energy density is greater than that of ionized air, and, therefore, apparently suspect.

Case 7. Ball-lightning-like phenomena have also been generated by machines. A rather unique case involves the well-documented accidental formation of fireballs aboard certain submarines by Silberg (1962, 1965). A fireball was formed by intense electrical discharges created during the switching of batteries and generators. The generators were used to charge the battery banks. Two generators were connected by a reverse current relay, and either generator could be connected to either of two battery banks.

The circuit breaker contacts of the relay were made of silver with copper extensions and a blowout coil. Occasionally, a highly charged battery bank was accidentally connected across a generator not in use. The resulting current was then disconnected by the reverse current relay. If an arc was formed across the silver electrode, the blowout coil would direct the arc onto the copper electrode extensions to minimize erosion of the silver electrode. Normally, the arc would be extinguished.

However, if there was an unusually large current in the arc, a green-colored fireball could develop from the contacts. The lifetime of the fireball was usually about a second. The green color was attributed to radiation from copper atoms in the fireball. A green wavelength results from the $^2P_{3/2}$–$^2D_{5/2}$ electronic transition in copper by electron impact excitation of the ground $^2S_{1/2}$ state. The energy of that 510.55 nm (1 nm $= 1 \times 10^{-9}$ m) wavelength is $\mathscr{E}_{\text{photon}} = 3.896 \times 10^{-19}$ J per photon. During tests it was found that the fireballs could only be formed if a certain power or current threshold was exceeded. A fireball was formed with a current (A) of 1.5×10^5 A and a voltage (V) of 260 V.

The associated power is given by

$$P = IV = 4 \times 10^7 \text{ W} \tag{4.34}$$

The mechanical switching time (t) was assumed to be 0.01 to 0.1 sec. The energy is given by the product of the power and the duration so that limits may be established as

$$4 \times 10^5 \text{ J} < E_T < 4 \times 10^6 \text{ J} \tag{4.35}$$

Assuming that 1%–10% of the energy expended was supplied to the formation of the ball after Silberg (1962, 1965), then

$$4 \times 10^3 \text{ J} < E_B < 4 \times 10^5 \text{ J} \tag{4.36}$$

As the fireball had an estimated diameter of 10–15 cm, then the uniform energy density, following equation (4.2), is

$$2.3\ \mathrm{J\ cm^{-3}} < \mathscr{E}_{\mathrm{BL}}\ (\text{case 7}) < 0.76 \times 10^{3}\ \mathrm{J\ cm^{-3}} \qquad (4.37)$$

It may be noted that the above calculations were based on Silberg's primary assumption that 1–10% of the available energy was supplied to the ball lightning. A more accurate value would be about 0.1% as determined by Powell and Finkelstein (1969, 1970) during laboratory experimentation. Under these conditions, the energy available to a 15 cm phenomenon could be as low as

$$E_{\mathrm{B}} \simeq 4 \times 10^{2}\ \mathrm{J} \qquad (4.38)$$

and the associated energy density would be

$$\mathscr{E}^{*}_{\mathrm{BL}}(\text{case 7}) \simeq 0.2\ \mathrm{J\ cm^{-3}} \qquad (4.39)$$

The experiments of Powell and Finkelstein (1969, 1970) are discussed in Case 9 and in Section 7.5. Briefly, they measured the visible and infrared radiant energy emitted by the laboratory-produced phenomenon as well as the energy available for its formation. The ratio of the two energies was determined to be about 0.001. This result is distinctive in that only Powell and Finkelstein were able to provide direct experimentally obtained measurement data regarding the formation and energy of a laboratory ball lightning.

Case 8. The intentional and accidental production of ball-lightning-like phenomena by high-potential generator and battery shortings has been reported several other times. A. T. Jones (1911) formed an apparent incandescent copper ball, but the details do not allow calculation of an energy density. However, Brand (1923) reported that a Norwegian hydroelectric engineer, Mr. A. Nielsen, produced luminous phenomena by shorting the contacts on a high-power direct-current generator. The generator was shorted by placing a water resistance in parallel with the shorting device. It has been speculated that the presence of the water aided the formation of the luminous phenomenon.

A reddish luminous mass with a diameter of about 5 cm was observed to float from the shorted contacts and remained visible for a few seconds. The event could be reproduced, apparently at will. Photographs of the luminous phenomenon were made by Nielsen and published by Brand (1923).

The generator used for the production of the luminous phenomena was rated at 10 MW at 12 kV. It is assumed that the mechanical shorting

of the generator occurred in 100 msec so that over 10^6 J would have been available for the formation of the phenomenon. In a manner analogous to that of Silberg (1962, 1965), 1%–10% of the available energy is assumed to have been used in the ball lightning formation, so that the uniform energy density, following equation (4.2), would be about

$$19 \leq \mathscr{E}_{\mathrm{BL}}(\text{case 8}) < 190 \text{ J cm}^{-3} \tag{4.40}$$

The energy density would be somewhat lower by using the results of the experiments of Powell and Finkelstein (1969, 1970) as discussed in Case 9 and in Section 7.5. The energy available to a ball lightning phenomenon was measured as only 0.1% rather than 1–10% as assumed by Silberg (1962, 1965). Therefore, the uniform energy density could have been

$$\mathscr{E}^*_{\mathrm{BL}} (\text{case 8}) \simeq 15.3 \text{ J cm}^{-3} \tag{4.41}$$

Brand also reported that Nielsen had made other observations of high power generator shortings which had also produced luminous phenomena. If the power available from the shortings was similar then the resulting energy density would be equivalent.

Case 9. Powell and Finkelstein (1969, 1970) experimentally produced a long-lived, luminous, globular mass in air at atmospheric pressure. They used focused electromagnetic radiofrequency excitation of air molecules to produce the phenomenon, which continued to glow after the input excitation energy was terminated. The lifetime for an unconfined discharge was 0.2–0.4 sec and had a measured temperature of 2000–2500°K. The ball was reported to have occasionally decayed by explosion.

The visible, infrared, and total radiant power of the phenomenon in air was measured as decreasing somewhat linearly from about 10–40 watts in about 300–500 msec. The energy was determined by integration with respect to time. The shape and amplitude of the curves were somewhat dependent upon the electrode material. The energy density was calculated from the measured data assuming an equivalent 6-in.-(15-cm-) diameter air plasma sphere. The average energy density was

$$\mathscr{E}_{\mathrm{BL}}(\text{case 9}) \simeq 5 \times 10^{-3} \text{ J cm}^{-3} \tag{4.42}$$

The experiments of Powell and Finkelstein (1969, 1970) are discussed in more detail in Chapter 7, Section 7.5. The experiments of Powell and Finkelstein (1969, 1970) are distinctive in that they measured the visible and infrared radiation from the laboratory phenomenon as

well as the energy available for its formation. This allowed the ratio of the two energies to be experimentally determined for the first time. A value of 1×10^{-3} was measured and may be noted as somewhat smaller than the values assumed earlier, for example, 1–10% by Silberg (1962, 1965).

Case 10. Other investigators, such as Nauer (1953), Fehr (1963), and Barry (1968a,c) designed experiments to inject energy into regions of air doped with active molecules. Air at atmospheric pressure was admixed with hydrocarbon molecules at low partial pressures, and dc discharges were generated within the gas mixture. Low-density hydrocarbon combustion phenomena were observed which resembled ball lightning.

The experiments of Barry (1968a,c), for example, were conducted in an enclosed laboratory volume of air at atmospheric pressure into which measured amounts of propane gas were added. A capacitor bank rated at 5 μf at a voltage of 10 kV was used to produce a dc spark with a duration of the order of 1 msec. The discharge produced a luminous, yellow-green, spherical ball which had a diameter of about 4 cm and moved about the chamber during its brief 1–2 sec life.

The luminous ball was interpreted as a combustion phenomenon and recognized as representing one form of ball lightning. Based upon the energy available, and using the ratio of the emission energy to input energy of 1×10^{-3}, as determined by Powell and Finkelstein (1969, 1970), a uniform energy density of

$$\mathscr{E}_{\mathrm{BL}}(\text{case } 10) \simeq 7 \times 10^{-3}\ \mathrm{J\ cm^{-3}} \qquad (4.43)$$

may be deduced. The experiments of Barry (1968a,c) are discussed in Section 7.3 and those of Powell and Finkelstein (1969, 1970) in Section 7.5.

Case 11. The experiments of Nikola Tesla in Colorado Springs, Colorado during the period 1899–1900 have been occasionally referenced as an example of one means of creating artificial ball lightning. However, the details of the experiments have remained largely unknown as a result of the lack of published information. Tesla (1904) made only brief reference to his experiments, indicating that he had artificially produced fireballs. It has only been recently that some specific information and details of the 1899 experiments have become widely available. General information has been discussed in the popular literature by Bass and Golka (1976), Blake (1977), Golka and Bass (1977), O'Neill (1971), Shunaman (1976), and Snigier (1976). More specific and direct information is contained in Tesla's diary of the

Colorado Springs experiments, which remained unpublished until late last year (Tesla, 1978).

Tesla apparently produced the artificial fireballs several times with a Tesla coil operated at ≃50 kW. The diameter of the fireball was noted as 0.75–2.5 in. (1.9–6 cm) and the life as a perceptible interval of time. The coil was operated at a peak voltage of 12.5 kV and produced about 12 J per pulse. Golka and Bass (1977) reviewed Tesla's hypothesis that localized heating of a lightning channel leads to fireball formation. The concept, noted in Tesla (1978), suggests that the internal energy of the ball is derived from the coil pulse energy and equal to the kinetic energy (pressure × volume).

The energy relation was given by

$$E = \frac{P_0 V}{\gamma - 1} \tag{4.44}$$

where P_0 is the pressure, V is the volume, and γ is the ratio of specific heats, $\gamma = 7/5$ for air. The ratio of the internal energy of the fireball to the coil pulse energy is given by n. The ratio of the internal pressure of the fireball to atmospheric pressure is denoted by ϵ. The ratio n/ϵ is a measure of the fireball efficiency and

$$\frac{n}{\epsilon} = \frac{4\pi P_0 R^3}{3(\gamma - 1)E_0} \tag{4.45}$$

Allowing a diameter of $2R = 3.8$ cm (1 in.) for a fireball, in agreement with the observations of Tesla (1978), and $E_0 = 12$ J, then

$$\frac{n}{\epsilon} \sim 0.6 \tag{4.46}$$

The interpretation of $n/\epsilon = 0.6$ is that with $\epsilon P_0 \simeq 10$ Torr (1 Torr = 1/760 atmosphere), agreeing with gas discharges, then $n \sim 0.006$, agreeing with the magnitude of that assumed by Silberg (1962, 1965) and just somewhat larger than that experimentally determined by Powell and Finkelstein (1969, 1970).

The corresponding energy density would be, following equation (4.2), as $E = \cong 0.006 \times 12 \text{ J} = 0.07$ J, then

$$\mathscr{E}_{BL}(\text{case 11}) \simeq 2 \times 10^{-3} \text{ J cm}^{-3} \tag{4.47}$$

Further details of the Tesla experiments are discussed in Chapter 7, Section 7.5.

Case 12. Another value for the energy density of ball lightning may be derived by considering its reported luminosity. A number of witnesses to ball lightning events have indicated that the brightness of the

phenomenon was similar to that of a low-power light bulb. Some experimental evidence is available that supports this observational characteristic. Powell and Finkelstein (1969, 1970) made radiance measurements of the glowing, long-lived air mass produced by molecular excitation. The initial radiative power was of the order of 10 W and decreased approximately linearily with time.

The uniform energy density associated with a 10-cm-diameter ball with a 1-sec lifetime and a radiated power of the order of 10 W, follows from equation (4.2):

$$\mathscr{E}_{BL}(\text{case } 12) \simeq 1.9 \times 10^{-2} \text{ J cm}^{-3} \tag{4.48}$$

The value for the energy density is quite low in comparison with most of the values previously deduced.

If we again assume that one atom or molecule per radiated photon was involved, we may calculate a density for the responsible atoms or molecules. Allowing that the ball color was 6000 Å wavelength (λ) with $h\nu = 3.3 \times 10^{-19}$ J per photon, then the number of atoms or molecules involved would be

$$N \simeq 5.8 \times 10^{16} \text{ cm}^{-3} \tag{4.49}$$

where $\nu = c\lambda^{-1}$ and c is the speed of light, $c = 3 \times 10^{10}$ cm sec^{-1}. The value of N is comparable to that reported by Powell and Finkelstein (1969, 1970) for the long-lived, experimentally produced, luminous air mass.

It would appear that the discussion near equation (4.56) regarding the density of excited atoms and electrons of several types of plasmas and the density of normal air at standard temperature and pressure may be applicable to the result here. The results suggest that a relatively low density of excited air molecules or atoms may be responsible for a luminous ball-lightning-like phenomenon.

Case 13. The energy density of ball lightning may also be estimated from the explosive decay characteristic frequently reported for the phenomenon. An acoustical noise of sufficient intensity to be detected by the observer may be related to the source power—here, the ball lightning. It must be assumed for this estimate that the radiated acoustical power is essentially contained within the audible frequency range. The power density so calculated is a lower limit as it does not include the other power losses due to radiative and convective processes.

The sound-energy density at a distance from the acoustical source is given by

$$D = \frac{p^2}{\rho_0 c_1^{\,2}} = \frac{p^2}{\gamma P_0} \tag{4.50}$$

where γ is the ratio of specific heats for the gas ($\gamma = 1.4$ for air), c_1 is the local sound velocity, p is the pressure perturbation, P_0 is the local barometric pressure, and ρ_0 is the density of the medium. D has units of J cm^{-3}. Consult Gray (1957), Chapter 3.

The sound intensity at a distance from the source is given by

$$I = \frac{p^2}{\rho_0 c_1} \tag{4.51}$$

I has units of W m^{-2}. The normal barometric pressure is .760 mm (29.9 in.) of mercury or about 10^6 dyne cm^{-2} at standard temperature. The minimum detectable sound level is

$$P_{min} \simeq 2 \times 10^{-4} \text{ dyne cm}^{-2} \tag{4.52}$$

and a deafening sharp noise level would be about 55 dB higher. This level would be somewhat greater than the recommended acceptable level for open rooms.

Consequently,

$$I_{min} = \frac{P^2_{min} c_1}{\gamma P_0} \times 3 \times 10^5 \tag{4.53}$$

and $I_{min} \simeq 3 \times 10^{-3}$ W m^{-2}. We assume spherical propagation from the acoustical source and negligible losses, so that the ball lightning is considered to be a point source. The source power is then related by the inverse R^2 law to that detected, and assuming $R = 10$ m,

$$I_{acoustical} \simeq 3 \text{ W} \tag{4.54}$$

It is further assumed that any detonation would occur in 0.1 sec or less and expend as much energy as would have been available for radiation if the ball had continued to exist for its full ~ 1-sec life. We then consider the total energy available to the ball lightning to be about 3 J.

The corresponding energy density is then related by equation (4.2). Assuming a 10-cm-diameter detonated ball lightning, the energy density would be greater than

$$\mathscr{E}_{BL}(\text{case } 13) \sim 6 \times 10^{-3} \text{ J cm}^{-3} \tag{4.55}$$

This value corresponds quite well with that deduced by Powell and Finkelstein (1969, 1970) for an experimentally produced glowing air mass. Refer to Chapter 7, Section 7.5 for additional information about this phenomenon.

Comments

There are a number of estimates of the energy density of a ball lightning based upon theoretical considerations or upon assumptions regarding an observation by a second party. Ashby and Whitehead (1971) reviewed various reports and discussions and considered an energy value of about 1×10^5 J as a reasonable estimate. The energy density for a 10-cm-diameter ball would be about 1.9×10^2 J cm^{-3}. Mathias (1926b) considered ball lightning to result from some type of burning matter, possibly produced by a lightning discharge and estimated an energy density value of 2.4×10^7 J cm^{-3}. The value was discussed by Balyberdin (1966) and Dmitriev (1967a) and recognized as being greater than the heat of explosion of TNT, and therefore unrealistic. The explosive energy of TNT is on the order of 2×10^3 J cm^{-3} so that larger energy density values must be suspect. An energy density value of 2.8×10^5 J cm^{-3} was calculated by Balyberdin (1966) for an explosive ball lightning which was reported to have caused a mud hut to collapse. An in-depth evaluation of this report was not possible because the original report was unavailable.

Neugebauer (1975) expanded upon the quantum mechanical model for ball lightning which he had suggested earlier (Neugebauer, 1937) and deduced an energy density value of 57.3 J cm^{-3} based upon a diameter of 20 cm. One of the earliest suggestions was made by Thornton (1911d), who postulated that ball lightning was predominantly composed of ozone and could rapidly decompose to oxygen with an explosive decay. The energy of conversion was erroneously estimated as 1×10^7 J for a 50-cm-diameter sphere. The error arose from the use of inaccurate values for the heat of formation of ozone. The correct energy density would be about 6–7 J cm^{-3} as noted by Singer (1971) and later by Smirnov (1975, 1976, 1977) and Stakhanov (1976) in expanded discussions on the possible chemical nature of ball lightning.

It may be suggested that a practical upper limit for the energy density of ball lightning is the value associated with a fully ionized air plasma. Numerous speculations have been made proposing that an ionized region in air could be created by some infrequently occurring peculiarity of a lightning discharge. The termination of a linear discharge, for example, might deposit sufficient energy in a small volume to create a fully ionized air mass.

The full ionization of air occurs at an energy $\simeq 39$ eV. The ionization of N_2, the main constituent of air, occurs at about 15.6 eV, forming N_2^+. The dissociation of N_2 into two neutral N atoms occurs at about 9.8 eV and the ionization of atomic N occurs at about 14.5 eV. The

conversion to energy units is given by 1.6×10^{-19} J eV^{-1}. The number of air molecules per unit volume at standard temperature and pressure is $L_0 = 2.69 \times 10^{19}$ cm^{-3}.

If only molecular ionization is considered, then to form a ball-shaped medium of N_2^+, the energy density would be

$$\mathscr{E}_{\text{ion-air}} \simeq 65 \text{ J cm}^{-3} \tag{4.56}$$

The energy density of a fully ionized air plasma formed of N^+ atoms would be

$$\mathscr{E}^*_{\text{ion-air}} \simeq 170 \text{ J cm}^{-3} \tag{4.57}$$

A similar value for the energy density of fully ionized air was calculated by Ritchie (1963). However, as was indicated by Tanenbaum (1967), the ionized particle density for a gas discharge has a range of $N = 10^{10}$–10^{14} cm^{-3}. Consequently, if these values are applicable to an atmospheric ball lightning plasma, we would expect an energy density of

$$\mathscr{E}_{\text{discharge-air}} \lesssim 1.7 \times 10^{-3} \text{ J cm}^{-3} \tag{4.58}$$

It is difficult to estimate the stability of a small volume of fully ionized air. Various plasma, thermal transport, and diffusion effects would rapidly eliminate a fully ionized air mass. A fully ionized air plasma would be expected to decay in about 10 μsec at atmospheric pressure according to Kapitza (1955, 1961). Low-pressure radiofrequency discharge experiments by Sinitsyn (1977a) have indicated the existence of an afterglow continuing after the excitation power was terminated. The lifetime of the plasma was of the order of 1 μsec. A partially ionized air mass at atmospheric pressure might exist longer, perhaps as long as 1 sec, agreeing with observations. A number of investigators, such as Finkelstein and Rubinstein (1964) and Pozwolski (1977), have seriously advanced the plasma concept for ball lightning, and it remains one of the most useful available.

4.3. Energy Interpretations

It has been occasionally suggested that more than one form or type of ball lightning exists in nature. This condition has been implied by observations during which, on one hand, damage and harm have been reportedly caused by some ball lightning events and, on the other hand, no ill effects were reported for other ball lightning events. In addition, ball lightning has been reported to decay either silently or explosively. The explosive decay has been assumed to be more energetic than the

silent decay. In order to evaluate the possibility of at least two forms of ball lightning, the energy density values and their distribution have been analyzed. The various energy density values and the associated parameters are noted in Table 4.1.

It must be noted that the accuracy of the energy density calculation may be correct only to the order of magnitude, and systematic errors may increase the inaccuracy. Such errors could be introduced, for example, by the difference between the reported and the actual diameter since halation effects would suggest a diameter larger than the actual size. The visible diameter could also be smaller than the actual diameter due to our lack of firm data regarding the emission of infrared radiation and the radial energy profile. The sensitivity of the energy density values to the error in the reported diameter is indicated by the derivative of the energy density with respect to the diameter D. A 30% error in the reported diameter, for example, leads to a 100% error in the value of the energy density. Such inaccuracies in reporting may account for much of the conflicting nature among reports and the deduced energy density values.

The reliability of the energy density values may, therefore, be reasonably questioned. An absolute reliability and confidence criteria cannot be applied to the observational data due to the unknown accuracy of the interpretation of the reported events. A relative reliability, reflecting the consideration of physical limits may be applied to the values deduced from observations. Values greater than about 1×10^3 J cm^{-3} are considered excessively large and improbable. Balyberdin (1966) and Dmitriev (1967a), for example, noted the implausibility of such values as the explosive energy of TNT is of the order of 2×10^3 J cm^{-3}. In addition, an upper limit may be imposed by physical considerations, such as that of a fully ionized air plasma, and would have an energy density of about 1.7×10^2 J cm^{-3} as discussed by Ritchie (1963).

The acceptance of inaccurate and unreasonably large energy density values by many invesigators has, of course, been popular, since it then enables some complicated and perhaps mysterious mechanism to account for the large energy content. However, it is highly unlikely that some natural energy source internal to the body of the phenomenon could remain undetected and unidentified. This difficulty was recognized by Kapitza (1955, 1961), and an external energy source was proposed to account for the continued existence of a ball lightning. Unfortunately, even after extensive investigation, no evidence for natural external energy sources has been reported. We must, therefore, seriously consider the improbability of extremely large energy density

Table 4.1 Compilation of the Presently Available Data on the Energy Density of Ball Lightning[a]

References	Basis of calculations	Total energy, J	Diameter, cm	Energy density, J cm^{-3}
	Observations and Discussions			
Balyberdin (1966)	Mechanical damage equated to ball energy	4×10^9	30	2.8×10^5
Morris (1936), Goodlet (1937), Carpenter (1963), Hill (1960), Altschuler, House, and Hildner (1970), Barry (1967a)	Thermal deposit equated to ball energy	— 3×10^6	— 10	1.9×10^3— 7.3×10^3 2.5×10^3 2.4×10^3— 4×10^3 2.5×10^3
Anderson and Freier (1972)	Thermal damage equated to ball energy	9×10^5	10	1.7×10^3
Stenhoff (1976), Wooding (1976)	Thermal damage equated to ball energy	3×10^3	2	8.7×10^2
Covington (1970) Zimmerman (1970)	Thermal deposit equated to ball energy	1×10^5	15	85
Marcet (1888), Altschuler, House, and Hildner (1970)	Mechanical damage equated to ball energy	3×10^6	60	26
Wittmann (1971)	Thermal damage equated to ball energy	1.9×10^4	12	21
Dmitriev (1969)	Molecular residue equated to energy of formation	530	14	0.4
	Experiments			
Silberg (1962, 1965)	Electrical short dissipation related to ball energy	4×10^4	15	23
Brand (1923)	Electrical short dissipation related to ball energy	1×10^3	5	15
Barry (1967a, 1968a,c),	Formation energy of hydrocarbon	0.25	4	7×10^{-3}

Table 4.1 (Continued)

References	Basis of calculations	Total energy, J	Diameter, cm	Energy density, J cm^{-3}
	Experiments (continued)			
Fehr (1963), Nauer (1953)	combustion related to ball energy			
Powell and Finkelstein (1969, 1970)	RF discharge phenomenon, energy content measured	10	15	· 5×10^{-3}
Tesla (1904, 1968), Bass and Golka (1976), Golka and Bass (1977)	Formation energy of high voltage discharge related to ball energy	0.07	4	2×10^{-3}
	Models			
Mathias (1926b), Teletov (1966a–c)	Energy of burning matter formed by lightning discharge equated to ball energy	—	—	2.4×10^{7}
Kozlov (1975, 1978)	Energy of lightning discharge equated to ball lightning	1×10^{6}	6–3 × 10^{2}	2×10^{2}
Richie (1963)	Energy density of fully ionized plasma at STP	—	—	170
Neugebauer (1937)	Energy of quantum mechanical gas equated to ball energy	2.4×10^{5}	20	57
Thornton (1911), Singer (1971), Smirnov (1975, 1976, 1977), Stakhanov (1976)	Energy of ozone conversion to oxygen equated to ball energy	4×10^{5}	50	6

[a] The data have been divided into the three categories to emphasize the source of the data. The values should be accepted as having only order of magnitude accuracy due to the subjective manner in which the dependent parameters were determined. The observational values were generally determined by the first author using the method of evaluation noted and/or by subsequent investigators at a later time. It is believed that the reliability of the experimental data is greater than that of the other sources due to the relatively controlled nature of the investigations. The energy density values attributed to Barry (1968a,b), Brand (1923), and Silberg (1962, 1965) reflect corrections made by using the measured results of Powell and Finkelstein (1969, 1970) to replace assumptions made by the three original authors. The reliability of values greater than about 2×10^{2} J cm^{-3} is questionable due to the physical limits noted by Ritchie (1963) and others. A median ball lightning energy density the order of 1 J cm^{-3} is suggested.

values and accept the range of about 2×10^{-3}–2×10^{2} J cm^{-3} as shown in Figure 4.1 as being more probable.

Such a range of energy density values does not preclude a large energy dissipation, since a 30-cm diameter ball with a maximum energy density of about 2×10^{2} J cm^{-3} could liberate about 1×10^{6} J and account for many destructive reports. Such energy liberation capability is in the range of that discussed, for example, by Kozlov (1978c). If we accept the upper range as about 2×10^{2} J cm^{-3}, that is, essentially the plasma limit, ball lightning may be removed from the arena of myth and speculation.

It must also be recognized that the data here may not be truly representative, since so little is available compared to the total number of observations. The number of ball lightning reports number over 1000 as collected by Barry (1979),yet only about 12 observational reports are detailed enough to allow an estimate of the energy density. Since ball lightning is considered to be a relatively rare event with an occurrence frequency of the order of 1×10^{-8} to 1×10^{-9} km^{-2} min^{-1} as deduced by Arabadji (1976), Brand (1923), Norinder (1939) and Tompkins, Rodney and Gooding (1975), one might expect that only those with relatively high energy content would be reported. As a result, estimates based on observations alone may yield energy density and energy content values greater than the true range. The phenomenon experimentally produced by Powell and Finkelstein (1969, 1970), for example, had an energy density of the order of 5×10^{-3} J cm^{-3}.

In view of the large range of possible energy density values as indicated in Table 4.1, and the observations of two decay modes, the possibility of at least two forms of ball lightning, one energetic and the other less so, would appear probable. In order to evaluate this possibility, and to attempt to reveal the fundamental nature of the form of the phenomenon, the energy density data were evaluated in a graphical manner.

A normal graphical distribution of the experimentally and observationally deduced energy density data from Table 4.1 was used. The less reliable data, for example, those deduced from models and estimates, were not included. A normal distribution was used as it is invariant to the order of the data. The distribution was obtained by plotting log base 10 of the energy density value versus the percent position of the individual entry in the data set relative to the total number of entries in the set. If only one type of ball lightning exists, the normal distribution should yield a single slope; if multiple types exist, then multiple slopes should be apparent.

The normal distribution of the ball lightning energy density data

of Table 4.1 is shown in Figure 4.1. Multiple data for the same event, such as that for the first entry in Table 4.1, were reduced to a single average value. The three values in Table 4.1 noted for Barry (1968a,c), Brand (1923) and Silberg (1962, 1965) were those calculated using the more correct ratio of the phenomenon energy to that available for its formation as deduced from the experiments of Powell and Finkelstein (1969, 1970). Refer to Case 7, Case 8, Case 10, and Section 7.5.

A best fit straight line has been drawn through the data points in Figure 4.1. Although a single slope fit to the data is not exact, it is considered appropriate relative to the accuracy of the data. A multiple slope does not appear to be as applicable. Consequently, based upon

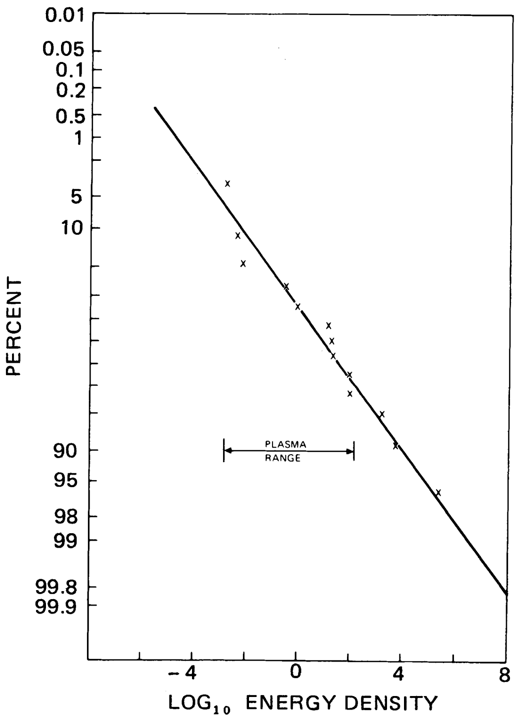

Figure 4.1. Normal distribution of the energy density values of the natural ball lightning observations and experimental observations summarized in Table 4.1 when arranged in descending numerical order. The distribution was made by plotting log base 10 of the energy density values versus the percent position of the individual member of the data set relative to the total number of entries in the set. The graph indicates a single slope for the data suggesting only one form of ball lightning in nature.

the data available, and the evaluation used, it would appear that only one form of ball lightning exists, in contrast to previous assumptions.

The evaluation of the available ball lightning energy density data indicates two new features. Ball lightning may be a phenomenon of relatively low energy density with a median value of the order of 1 J cm^{-3} and a range of about 2×10^{-3}–2×10^{2} J cm^{-3}. In addition, it would appear to be a phenomenon of single form having the possibility of both silent or explosive decay.

4.4. Temperature

The temperature of a ball lightning might be deduced from its observed properties. The visible color of the radiation emitted by the ball lightning could be related to the irradiance of a blackbody emitter. A blackbody at a temperature T will have a total power per unit surface area over the frequency range $d\nu$ given by Planck's equation,

$$dI_\nu = \frac{2\pi h}{c^2} \frac{\nu^3 d\nu}{(e^{h\nu/kT} - 1)} \tag{4.59}$$

where ν is the frequency in Hz, $h = 6.625 \times 10^{-34}$ J sec^{-1} is Planck's constant, $c = 3 \times 10^{10}$ cm sec^{-1} is the velocity of light, $k = 1.38 \times 10^{-23}$ J $°K^{-1}$ is Boltzman's constant, and T is the absolute temperature in degrees Kelvin (0°C = 273°K).

The wavelength at which a blackbody will emit maximum power per unit wavelength is given by

$$\lambda_m T = 2898 \times 10^{-4} \text{ cm °K} \tag{4.60}$$

so that, for example, a red ball lightning with $\lambda_m = 6300$ Å would have a temperature of

$$T_R \simeq 4600 \text{ °K} \tag{4.61}$$

A yellow ball lightning with $\lambda_m = 5800$ Å would have a temperature of 5000 °K, a blue ball lightning with $\lambda_m = 4700$ Å would have a temperature of 6200 °K, and for a white ball lightning, the temperature could be 10000°K or higher. If we refer to those ball lightning observations that report a blue or blue-white central core surrounded by a flame halo, then it would appear that the temperature of ball lightning varies along the radius.

It must be remembered that the use of the relation in equation (4.60) is dependent upon the color identification by the observer. The identification of color is in turn dependent upon the color perception response of the human eye. The interaction of light with the human

eye has been the subject of recent investigation. The results of the investigation of Dmitriev, Emel'yanov, Kashintsev, Kulikor, Solov'ev, Stel'makh and Cherednichenko (1979) has shown that near infrared radiation (near 1 micron wavelength which is normally considered beyond normal human vision) is perceived as a color near one-half of the infrared wavelength. Consequently, the temperature of ball lightning, using the reported color as an indicator, could be less than that indicated by equation (4.60) by a factor of two if the phenomenon has strong emissions in the near infrared. The variable perception of infrared light between observers could also possibly account for some of the variability between ball lightning reports.

The temperature of one ball lightning phenomenon was estimated by Dmitriev (1969). The observation was discussed previously in the earlier section on energy values (Case 4). During the observation, samples of the air surrounding the ball lightning were taken. The concentration ratio of ozone to nitrogen oxide was found to vary from about 0.8 to 2.5. Four samples were taken. Later glow discharge experimentation verified that the ratio could vary from 1 to 6, depending upon the voltage difference between the electrodes. As the voltage increased, the ratio decreased. The measured ratio corresponded to a potential of about 300–400 kV between the ball and the earth.

It was also found that the ozone to nitrogen oxide ratio decreased as the temperature of the discharge increased. A ratio of 0.8 was comparable to a temperature of about 4000°K. Visual observations suggested a higher temperature by analogy to the brightness and color of a plasmatron object. Based upon that concept, the temperature of the ball lightning may have been 14000°K.

The existence of a gas sphere essentially composed of free electrons and positive ions was investigated by Neugebauer (1937). The result was the calculation of a temperature of the plasma sphere. The number of electrons and positive ions was assumed equal so that small-scale and overall electric neutrality would result. It was further assumed that the plasma gas was formed of air molecules so that the density would be equivalent to that of the surrounding air.

The analysis followed a quantum mechanical approach to show that an ionized gas mass could exist in a metastable equilibrium. The cohesion of the mass would have to be supplied by the quantum mechanical exchange energy of the electron gas. The electron exchange energy was described as a weak attractive force which occurs between electrons of equal and opposite spin. The normal repulsive electrostatic force could be canceled because of the positive ions imbedded in the electron gas. Neugebauer also ignored the polarization energy as it

would be small in comparison to the exchange energy. The exchange energy would thereby be dominant and would provide the cohesive force for a quasistable plasma at temperature T.

The average value of the exchange energy of an electron contained within an electron cloud of density n was shown by Neugebauer to be given by

$$E_E = -\frac{e^2nh^2}{8\pi mkT_E} \tag{4.62}$$

where e is the electron charge (1.6×10^{-19} C), h is Planck's constant (6.625×10^{-34} J sec), m is the mass of the electron ($m = 9.1 \times 10^{-31}$ kg), and k is Boltzmann's constant ($k = 1.38 \times 10^{-23}$ J °K^{-1}).

It was further assumed that the ball would be stable as long as the exchange energy was balanced by the kinetic expansion forces of the gas. Maxwell–Boltzmann properties were assumed so that the thermal energy is given by

$$E_{\text{th}} = \tfrac{3}{2}kT_E \tag{4.63}$$

The ball would be expected to have stability as long as $E_E \geq T_{\text{th}}$. Equating the two energy terms would establish a ball lightning temperature. Therefore,

$$T_E{}^2 = \frac{e^2nh^2}{12\pi mk^2} \tag{4.64}$$

The value of T_E was calculated using the density of air, $n = 2.69 \times 10^{19}$ electrons cm^{-2}, so that

$$T_E = 632°\text{K} \tag{4.65}$$

The associated energy density would be

$$\mathscr{E}_E = 0.35 \text{ J cm}^{-3} \tag{4.66}$$

The result suggests that an electron–positive-ion plasma that is electrically neutral over small distances could be dominated by electron exchange forces and might remain stable if the thermal energy remains rather low. The practical influence of the energy available due to the initial ionization of the medium has not been addressed. It might also be expected that the ionized medium would experience rapid recombination with an associated short lifetime.

The concept of a calculated color temperature as representative or indicative of a true ball lightning temperature may not necessarily be applicable. There are several natural examples of light emission without an associated thermal relationship. Bioluminescence, the natural emis-

sion of light by living organisms, has been widely observed and studied. Several examples include certain species of bacteria, fungi, protozoa, fish, and insects. Perhaps the most common, or at least the most familiar, is the firefly.

Bioluminescence results from chemical reactions which yield a molecular product in an excited energy state with subsequent decay and light emission. The fundamental reactions are known as chemiluminescence reactions and can be essentially duplicated in the laboratory.

The light emission from the firefly also results from a chemiluminescence reaction involving the enzyme-catalyzed oxidation of the firefly luceferin molecule. The responsible chemical reactions have been extensively studied, for example, by Seliger and Morton (1968) and White, Rapaport, Seliger, and Hopkins (1971). The light is produced by intramolecular transitions, and one light photon is produced per luciferin reaction. The energy for the transition is from the chemical reaction and is not due to thermal sources.

The characteristics and properties of the light emitted by bioluminescence and chemiluminescence are not related to a color temperature. The reactions produce visible light at room temperature. Consequently, the true or system temperature is about 20°C (300°K) in conrast to a color temperature, following equation (4.60), of about 5000°K. It has been speculated that the visible light from a ball lightning is due to some chemiluminescence reaction, similar to that responsible for the firefly emissions.

Recent studies by Powell and Finkelstein (1969, 1970) have verified that molecular interactions are responsible for the visible light emissions from one type of laboratory-produced, persistent, glowing air mass. The reactions are really collisional energy exchange reactions rather than chemical reactions. Energy is absorbed and stored in metastable states from the energy source and transferred to another molecule with subsequent radiation. Refer to Section 7.5, Electrodeless Discharges.

The light emissions were not of thermal origin and color temperatures were not applicable. It may be inferred that to apply a color temperature to the ball lightning phenomena may not be at all appropriate.

4.5. Radiation

A number of suggestions regarding the radioactive nature of ball lightning have been advanced in attempts to explain observations. Altschuler, House, and Hildner (1970) suggested a series of nuclear

reactions involving ^{16}O, ^{15}O, ^{14}N, and ^{17}F and the production of protons, positrons, and gamma rays. The gamma rays would have an energy of about 0.5 MeV and would have a range in air of several hundred meters. Hill and Sowby (1970) indicated that such gamma radiation would constitute a grave health hazard for an observer. At a range of 2 m, the dose rate would be from 175 to 325 rad sec^{-1}. This dose rate would cause radiation sickness, perhaps even death.

It was suggested that the thermoluminescence properties of any suitable material contacted or in the water vicinity of a ball lightning should be examined. If ball lightning has a radiation property, thermoluminescence might be induced in certain materials. Thermoluminescence is a property of solid materials to emit light during heating. A rock normally emits light upon first heating but exhibits no further luminescence if cooled and reheated. However, if after being heated and cooled the rock is then irradiated with high-intensity x rays or gamma rays, the thermoluminescence property is restored.

The theory of luminescence suggests that the radiation causes electron excitation with associated mobility in the conduction band of the crystalline structure. The excited electrons become bound in electron traps—metastable energy levels termed *F* centers. The electrons are released from the traps upon heating and give rise to the observed radiation-induced thermoluminescence. A radiation dose rate of several hundred rad per second could be detectable in an appropriate material. If a ball lightning life of more than 1 sec were appropriate—say about 3 sec—then 10^3 rad may have been received by a nearby object.

Mills (1971) investigated the gamma-ray effects to material from a church steeple which was reportedly damaged by ball lightning in 1638. Tomlinson (1889) gave a dramatic report of the thunderstorms, its associated ball lightning, and the extent of the damage. Mills was able to examine a portion of the original steeple in a conventional manner for thermoluminescence. There was no evidence of increased thermoluminescence from any part of the steeple material. A portion was exposed to gamma radiation from a cobalt-60 source. The resulting thermoluminescence peak was detectable at 110°C and was not stable even at room temperature. The minimum detectable dose was about 100 rad. No evidence of exposure to an intense source of radiation was therefore obtained.

A similar thermoluminescence evaluation was made by Fleming and Aitken (1975) on bricks of a house reportedly hit by a ball lightning. The building material was only 25 years old and normal dosage rates were low, of order 0.5 rad per year. It was found that the material did not indicate exposure to a significantly large radiation source. Based

upon control samples and the sensitivity of the tests, the ball lightning radiation must have been less than 5 rad. The conclusions of Fleming and Aitken (1975) were therefore in agreement with those of Mills (1971). Consequently, we may conclude that ball lightning does not appear to produce gamma radiation at any significant dose level.

4.6 Magnetic Field

It has been assumed by a number of investigators of ball lightning events that electric and magnetic fields are associated with the phenomenon and are fundamental for its formation and/or existence. Only a few investigators have used observational characteristics to deduce electric and or magnetic field properties associated with a ball lightning.

Blair (1973) calculated that a ball lightning might have a magnetic field of order 150 G associated with its presence. The calculation was based upon an observation in 1811. The motion of a metal bell in a church steeple was reported to have been made more difficult by the sudden appearance of a ball lightning. It was assumed by Blair that a magnetic field associated with the ball lightning inhibited the motion of the metal bell.

Blair reasoned that the bell could be approximated as a disk rotating in a magnetic field. An electric potential would be generated by the passage of the magnetic flux lines through the metal, and given by

$$V = NHA \times 10^{-8} \tag{4.67}$$

where N is the rate of motion in revolutions per second of the disk of area A in the magnetic field of strength H in units of gauss, and V has units of volts.

The energy dissipated as an electric current flows in the metal with potential V and resistance R is

$$\mathcal{E} = 2V^2/R \tag{4.68}$$

The factor of 2 results from one revolution of the disk in the magnetic field. The units of $\mathcal{E}$ is watt seconds.

The work done was assumed to be equivalent to that required by a bell ringer to cause the bell to sound. A force of 10 kg weight through 1 m was assumed. The value of $\mathcal{E} = 100$ W sec results.

The resistance of the bell was taken as 3.5×10^{-6} ohm for an average diameter of 70 cm, a wall thickness of 7 cm, a wall length of 80 cm, and a bronze resistance of 18×10^{-6} ohm cm.

The equations were combined and $\mathcal{E}$ set to 100 W sec, so that a

value for H could be computed, and

$$H = 150\ \mathrm{G} \tag{4.69}$$

It was recognized that the value was only an estimate as a bell is not a disk but a hollow vessel. The resistance could not be exactly calculated, as the eddy current distribution and flow within the bell was not known.

The relatively strong magnetic field property for ball lightning suggested by this calculation is not supported by other observations. The result does suggest that if ball lightning has an associated magnetic field, it should also have a cylindrical current component and possibly rotational structure. The presence of a magnetic field could cause variations in its motion as its field would interact with that in the environment.

4.7. *Inferences*

It must be recognized that the margin of error in calculations of the type used in this chapter may be quite large. The data upon which the calculations are made are certainly incomplete, the events are not reproducible nor controlled, and the estimates are based upon assumed parameters. For example, the dimensions assumed for the ball lightning of 10–15 cm was chosen to match the estimates of observers.

If the true ball lightning diameter is greater than that observed, then the energy density values calculated could be smaller by some possibly significant factor. Muller-Hillebrand (1963, 1965) and Stekol'nikov (1955) reported an instance of lightning which penetrated window glass and produced a hole of about 1.6–1.7 cm diameter. A photograph of the window pane with an almost circular hole was reproduced by these authors and has been frequently attributed to a ball lightning. A similar photograph of a window pane with a small hole was discussed by Geddes (1939), and McIntosh (1973) and has also been attributed to a ball lightning.

Uman (1964) measured the diameter of a lightning channel as being of two types. Most were 2–5 mm or 2–5 cm in diameter, suggesting that the diameter of ball lightning, if it is in fact developed from normal lightning discharges, could have a core diameter smaller than 5 cm. This suggests that the observed diameter of 10–30 cm results after significant expansion of the ball from the linear channel dimension. Additionally, this may suggest a radial structure to the ball and its energy density, such as a high core value and a lower value in the outer area.

One may suggest that the visible ball lightning diameter does not

define a true boundary for the phenomenon but that a nonvisible outer region exists and extends to some distance to smoothly merge into the surrounding air. It is an unavoidable conclusion that the diameters reported for ball lightning observations are, in reality, too small. The boundary of a ball lightning cannot terminate at the apparent boundary defined by the radial range of the illumination. It is in keeping with our knowledge of natural things that sharp discontinuities are normally rare. The boundry may be vague, possibly changing with time and providing a smooth transition into the surrounding air.

The energy distribution of ball lightning may extend beyond the apparent visible boundary, perhaps for two to three more diameters. A twice larger diameter would, of course, reduce an energy density of 1×10^3 J cm^{-3} to an acceptable value of 1×10^2 J cm^{-3}.

The existence of a ball lightning establishes certain properties for the responsible formation process. The ball lightning energy must be self-contained or receive continuous input from the environment. Resonant electromagnetic radiofrequency radiation was suggested by Kapitza (1955a,b) as supplying the required energy to maintain a ball. Such radiation has not been found to exist in nature, though. Processes supplying self-contained energy sources have been suggested years ago by Hildebrandsson (1885), based upon hydrocarbon gas combustion, and by Neesen (1900), based upon vaporized metal atoms. Experiments have verified some of these early speculations and demonstrated more modern concepts, such as energy storage in molecular metastable energy states. Refer to Chapter 7, Sections 7.3, 7.4, and 7.5.

Energy must be lost from an energized (air) mass by acoustical radiation, optical and infrared radiation, convection, and collisional energy exchange with the surrounding medium. These losses must be balanced by the energy input from external sources, or by internal energy transfer and reorganization. It is likely that the unperturbed transfer of energy from the storage process to the radiative process is relatively slow, dependent upon collisional properties of the medium. Should some perturbation hasten the process, rapid transfer of energy and charges may occur which lead to the observed explosive decay. Consequently, we may speculate that the two forms of ball lightning decay do not represent two distinctively different forms of the phenomenon. The explosive decay mode is simply a modified form of the silent decay. The models of Powell and Finkelstein (1969, 1970) and Barry (1967a,b) are consistent with these concepts. The former, however, is more probable than the latter.

5

Ball Lightning Photographs

5.1. Photographic Evidence

Photographs of ball lightning occurrences are relatively few considering the large number of normal lightning photographs that have been made. A conservative estimate of the number of normal lightning photographs would be well over 10^5. We are aware of only about 60 photographs or drawings that have been published as those of natural ball lightning. Some, of course, are duplicate publications of an earlier original or a slightly different view of the same subject. Once these are separated out, there are only 24 individual and distinctly different photographs that have been available for evaluation. (Refer to Table 6.2, Chapter 6.) Moreover, analysis of each of these photographs, the associated reports, and the subsequent published discussion, allows us to conclude that most of these are spurious.

In evaluating the remainder, a scientist must remain skeptical until presented with substantial and definite evidence for examination. One cannot accept a photograph as a single complete verification. Rather, other kinds of evidence must be examined; these include multiwitness reports and physical effects caused by the phenomenon. Deduced evidence is accepted as supportive in nature rather than being primary. We must emphasize that the photographic evidence available does not by itself provide definite, substantial or complete documentation for the understanding and verification of the phenomenon of ball lightning.

The so-called ball lightning photographs illustrate the same discrepancies as are common with the ball lightning reports. One may appear perfectly spherical, another elongated, another apparently losing parts of its mass, another in random motion, another with linear motion, and others are obviously spurious. In general, the photographs reflect

the nature of the various reports: somewhat inconsistent and seemingly with little in common.

In order to make some sense and order, the photographs have been separated into eight classes or divisions. The division of the photographs into separate areas is based upon observed properties. Each division reflects a single common characteristic, easily identifiable and distinct from the other classes. The classes are as follows:

Class 1: Pulsating illumination
Class 2: Multiple path
Class 3: Lightning channel decay
Class 4: Pyrotechnic appearance
Class 5: Stationary image
Class 6: Uninterrupted singular trace
Class 7: Natural discharges
Class 8: Artificial phenomena

The eight classes reflect obvious distinctions between the various photographs and the numerous reports. The divisions also allow easy identification of spurious reports and photographs.

The importance of ball lightning photographs in providing a number of examples of the visual image of the phenomenon for study cannot be underestimated. In addition, photographs can provide much more information for evaluation than simple reports of observations. Unfortunately, ball lightning photographs are published much more infrequently than ball lightning reports. And since ball lightning events are considered to be rare occurrences, it should be clear that ball lightning photographs are rare indeed. It will also become clear that even though a number of photographs have been identified as being of ball lightning, most such identifications are erroneous and only a few are considered valid.

All of the references to photographs identified as ball lightning and associated discussions known to this author are listed in Table 5.1. Every known reference has been included, in the interest of completeness and for general use by other researchers.

5.2. Classes of Photographs

5.2.1. Class 1: Pulsating Illumination

This class is characterized by a single linear discontinuous streak on the photograph, apparently made by a single illuminated object whose intensity fluctuated as it moved.

Table 5.1 References to Reports or Discussions with Photographs or Drawings That Have Been Identified as Those of Natural or Artificial Ball Lightning

Abbot (1934)	Kolobkov (1951)
Arrhenius (1903)	Kuhn (1951)
Atkinson (1968)	Lane (1965)
Bailey (1977)	Leonov (1965)
Baltin (1902)	Mathouillot (1908)
Barry (1966)	Matthias and Buchsbaum (1962)
Bauer (1938)	Merhaut (1944)
Bauman(1937)	Muhleisen (1972)
Benedicks (1954)	Muller-Hillebrand (1963, 1965)
Bonacina (1946)	Norinder (1939, 1965)
Brand (1923, 1971)	Petersen (1954a–c)
Butz (1968)	Poulter (1935, 1954a,b)
Cade and Davis (1969)	Prochnow (1928, 1930a)
Cartwright (1938)	Raab (1940)
Charman (1972, 1976, 1979)	Ritchie (1959b, 1963)
Daerdaeevskii (1957)	Rossman (1949)
Davidov (1958)	Ruthers (1958)
Davies and Standler (1972)	Salanave (1965)
Dixon (1955)	Scheminzky and Wolf (1948)
Dmitriev (1971a)	Schneiderman (1934)
Dmitriev, Deryugin, and Kalinkevich (1973)	Scott (1955)
	Shagin (1960)
Dunn (1894)	Singer (1977)
Eriksson (1977a)	Stekolńikov (1943)
Geist (1949)	Teletov (1966a–c)
von Haidinger (1868a)	Tompkins and Rodney (1977)
Hatch (1958)	Tompkins, Rodney and Gooding (1975)
Holtzer, Workman, and Snoddy (1938)	Townsend (1895)
Holtzer and Workman (1939)	Trowbridge (1907)
Hubert (1975a)	Viemeister (1961)
Israel (1958, 1960)	Walter (1929)
Jennings (1962)	Wolf (1943b, 1956a,b)
Jensen (1933a,b)	Young (1934)
Kapitza (1958)	Zoege von Manteuffel (1938)
von Kilinski (1958)	Zschokke (1903)

The photographic appearance of this class of ball lightning is not greatly different from that of bead lightning; there is one very distinct difference, though. These phenomena occurred near the ground and observer, whereas the bead lightning events were distant and usually at cloud height. This class is also characterized by a number of spurious photographs and erroneous identifications. All have been published as examples of ball lightning.

Two photographs which illustrate a striking segmented appearance are shown in Figures 5.1 and 5.2, both from Dmitriev (1971a,b). The

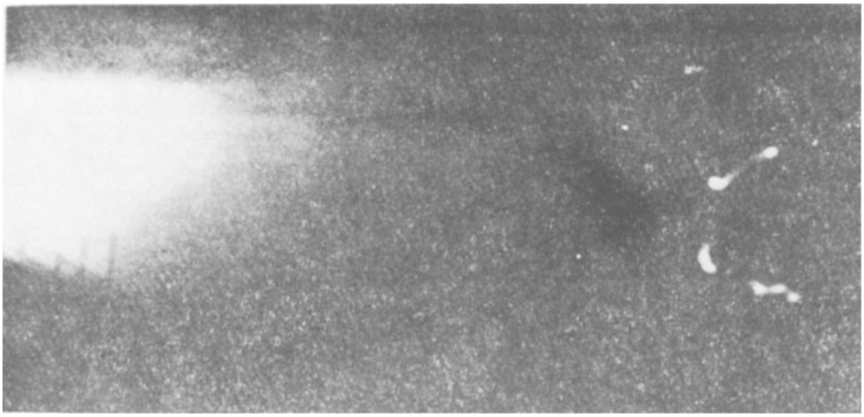

Figure 5.1. Still camera photograph made during a storm showing an intensity-modulated image which was identified as that of a ball lightning. Reprinted with permission from *Priroda,* Moscow, after M. T. Dmitriev, "Sharovyye Molnii: Novyye Nablyudeniya i Novyye Gipotezy," *Priroda,* No. 6, 1971, p. 50, English translation, "Ball Lightning: New Observations and New Hypotheses," NASA Technical Translation, F-13931, Sept. 1971.

photographs were obtained during a thunderstorm with normal lightning activity present. Figure 5.2 is an enlargement of the right-hand portion of Figure 5.1 to give a better view. The intensity modulation was investigated in some detail by Dmitriev, Deryugin, and Kalinkevich (1973), who determined the relative brightness along the length of the image. The modulation was apparently 100%. Close examination suggests three-dimensional motion. Figure 5.2 should be examined in relation to Figure 5.33, where a natural lightning discharge was recorded with a movie camera. Figure 5.33 and its associated study illustrates that natural lightning discharges are three dimensional in nature and can give a significantly different two-dimensional effect when recorded with a single-frame exposure.

It seems quite plausible to suggest that many of the so-called ball lightning photographs as recorded by a single-frame camera are of a natural lightning discharge as it followed its path over a small distance with rapid and random motion. The combination of the random motions over a small volume of space would result in that volume element having a larger current density than that of a linear segment. Consequently, that volume would appear brighter and with greater persistent luminosity than a linear segment of the discharge.

Perhaps the most controversial photograph reported to be that of a ball lightning is shown in Figure 5.3 from Jennings (1962) and reproduced by Lane (1965), Barry (1966), Atkinson (1968), Butz (1968),

and Cade and Davis (1969). This particular photograph has been the object of much discussion. The ball lightning event was not originally reported as having been observed firsthand but accidentally recorded on film during a thunderstorm. The slight blurring of the background was reported to have been caused by the photographer's involuntary muscular response to the lightning event. In the original photograph, one notices a color change in the dots along the path. It apparently begins as red, then changes to yellow, then to white. An apparent reflection of the image in the building windows may also be observed upon close inspection. Lane (1965) and Atkinson (1968) supplied further details not available in the report by Jennings (1962).

Figure 5.2. Enlargement of the intensity-modulated image shown in the right-hand portion of Figure 5.1. The trace, identified as that from a ball lightning, has been studied to determine the relative range of the intensity modulation along the trace. Reprinted with permission from *Priroda,* Moscow, after M. T. Dmitriev, "Sharovyye Molnii: Novyye Nablyudeniya i Novyye Gipotezy," *Priroda,* No. 6, 1971, p. 50, English translation, "Ball Lightning: New Observations and New Hypotheses," NASA Technical Translation, F-13931, Sept. 1971 and reproduced by M. T. Dmitriev, V. M. Deryugin, and G. A. Kalinkevich, "Optical Emission from Ball Lightning," *Sov. Phys. Tech. Phys.,* **17,** No. 10, 1973, p. 1724.

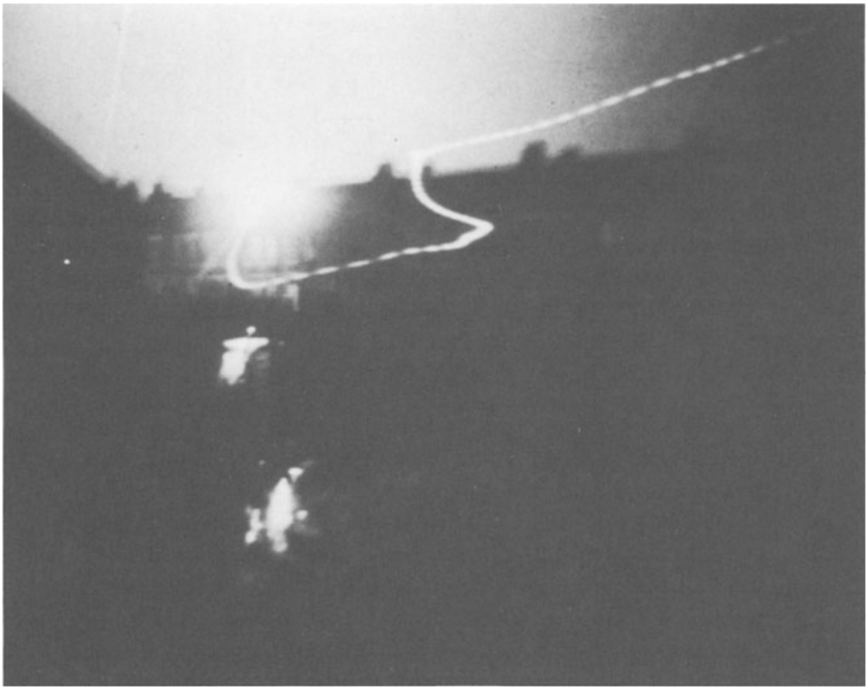

Figure 5.3. Still camera photograph of an intensity-modulated trace which was identified as that of a ball lightning. The phenomenon was not observed and it has been argued that the image is that of a street lamp and the modulation caused by camera motion. Reprinted with permission from *New Scientist,* London. This photograph first appeared in *New Scientist,* London, the weekly review of science and technology. Reprinted from R. C. Jennings, "Path of a Thunderbolt?," *New Scientist,* **13,** 1962, p. 156 and reproduced by: F. W. Lane, *The Elements Rage,* Chilton, New York, 1965, p. 165; by J. D. Barry, *Ball Lightning, a Natural Phenomenon in Atmospheric Physics,* M. S. thesis, California State College, Los Angeles, California, 1966; by B. W. Atkinson, "Riddle of Ball Lightning," *Geographical Magazine,* **41,** 1968, p. 204; by C. M. Cade and D. Davis, *The Taming of the Thunderbolts,* Abelard-Schuman, New York, 1969, dust-cover; by J. S. Butz, Jr., "Great Balls of Fire," *Air Force Magazine,* **51** (4), 1968, p. 149; and by D. W. Davies and R. B. Standler, "Ball Lightning," *Nature,* **240,** 1972, p. 144.

Although this photograph has been identified by many as an example of a ball lightning event, Davies and Standler (1972) critically evaluated the photograph and the scene of the event. They were able to identify the bright flare at the left of center with the position of a 140-W sodium vapor street lamp to an accuracy of about 1 ft. Even though the photographer insisted that the lamp was off at the time of

the event, Davies and Standler ascertained from the Electricity Board that it was in fact illuminated at the time of the recorded event.

A sodium vapor lamp in England is operated with an ac line frequency of 50 Hz (50 cycles per second). An ac electrically excited sodium vapor street lamp has intensity modulation of about 50% over the 0.01-sec half-cycle. The temperature of the sodium vapor may change about 1000°C over the half-cycle but the time average or root-mean-square value will remain constant. This means that a sodium vapor street lamp photographed with a moving camera could result in a quasilinear trace with an intensity-modulated appearance. However, any color change associated with the gas temperature would have to occur over each half-cycle rather than slowly along the total trace.

Davies and Standler (1972) report that the dotted appearance is also visible in the edge shadow, presumably the edge of the window frame through which the photograph was made. Since a dotted image could not have been superimposed on the interior of the window frame shadow, the interpretation of this event as being due to camera motion and a street lamp is unavoidable.

Additional communication with Mr. Davies (private communication, 1977) indicated that the color change that occurred in the upper right-hand corner is related to the sky darkening there and is associated with a vignetting effect. He was also able to reproduce the effect by photographing a street lamp. The photography of street lamps and the erroneous identification with natural lightning discharges has not been uncommon. Behn (1903) early recognized the common photography problem soon after Riggenbach-Burckhardt (1897) published photographs erroneously identified as bead lightning. Consequently, it is difficult to avoid the conclusion that many ball lightning photographs made with a hand-held, single-frame camera are caused by camera motion and artificial light sources, such as street lamps.

5.2.2. Class 2: Multiple Path

This class is characterized by a number of related, apparently duplicate traces on the photograph, possibly caused by a number of illuminated objects whose image paths track one another in a constant manner.

A number of photographs reported to be of ball lightning involve multiple and apparently duplicate paths. It would appear from evaluation of these photographs that several ball lightnings were moving together in unison thereby forming the recorded images. Occasionally,

these multiple paths appear to have intensity modulation, that is, a dotted appearance is also recorded. It is probable that these photographs are the result of camera motion and the identification as ball lightning is erroneous.

A good example is the photograph shown in Figure 5.4 after Abbot (1934). The photograph was originally made by H. Spickerman in 1908. The lightning was reported to have occurred at some distance above the ground. It was reported by Muller-Hillebrand (1963), who reproduced the photograph, that camera motion did occur during the event. This photograph has also been reproduced by Holtzer and Workman (1939). The photograph was reported to illustrate that a number of discharges could occur simultaneously, each responding in the same way to the local electric field and space charge distribution. However, camera motion did occur and it is now thought to be responsible for the traces.

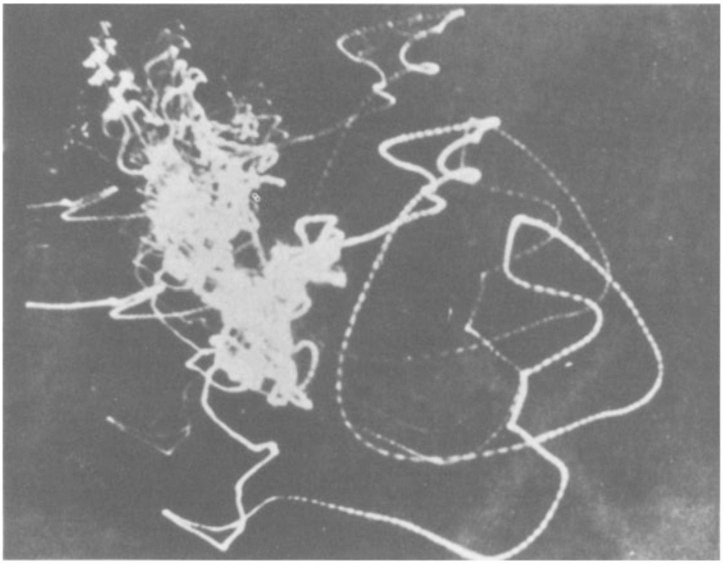

Figure 5.4. Still camera photograph made by R. J. Spickerman in 1908 during a lightning storm which supposedly recorded the trace of a series of related discharge paths. Camera motion is thought to be responsible for the traces. Reprinted by permission of the Smithsonian Institution Press from Smithsonian Miscellaneous Collections, Vol. 92, No. 12: Hodgkins Fund: "Remarkable Lightning Photographs," C. G. Abbot, Smithsonian Institution: Washington, D.C., 1934; and reproduced by R. E. Holtzer and E. J. Workman, "Photographs of Unusual Discharges Occurring during Thunderstorms," *J. Appl. Phys.*, **10,** 1939, p. 659; by D. Muller-Hillebrand, "Zur Frage des Kugelblitzes," *Elektrie,* **17** (7), 1963, p. 211; and by G. S. Teletov, "Ball Lightning," *Priroda,* No. 9, 1966, p. 84, English translation in JPRS 39032, U.S. Dept. of Commerce, Washington, D.C., 1966.

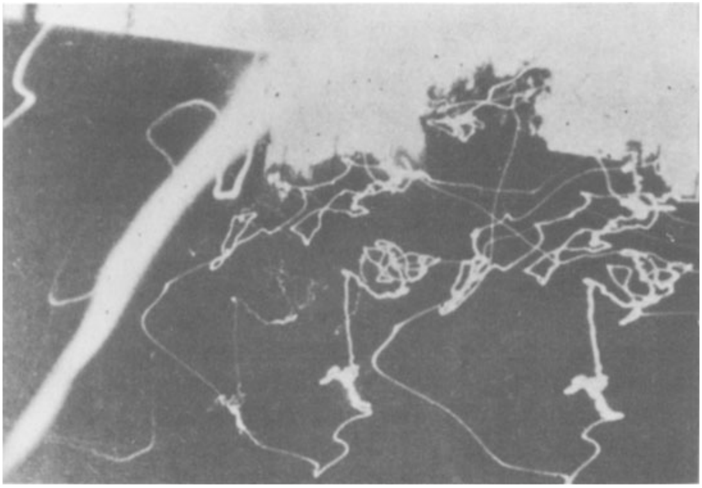

Figure 5.5. Still camera photograph reportedly showing multiple images of a lightning discharge reported to have been caused by ball lightning motions. Camera motion is suspected as being responsible for the duplicated traces. Reprinted with permission from *Elektrie,* after D. Muller-Hillebrand, "Zur Frage des Kugelblitzes," *Elektrie,* **17** (7), 1963, p. 211.

A similar photograph was also published by Muller-Hillebrand (1963) and is shown in Figure 5.5. The event occurred near the ground close to the observer and multiple images were recorded. At least three duplicate images paths are apparent in the photograph. A ball lightning entity was not reported by the observers and camera motion is suspected.

Another multiple-trace photograph reported to be that of ball lightning is shown in Figure 5.6 after Shagin (1960). The photograph was originally published as shown here; three quasivertical illuminated paths are visible. The photograph was reproduced by Teletov (1966a–c) but showing only one path in the reproduction of the image from the original. It is clear that the lower end of the trace ends with a lamp post. Contact with the photographer was not possible. However, we conclude that this photograph was due to camera motion and has been erroneously classified as that of ball lightning.

Other probably erroneously classified ball lightning photographs include that by Zoege von Manteuffel (1938) shown in Figure 5.7 and that by Young (1934) shown in Figure 5.8. The multiple trace is somewhat faint and is clearer to the left of the center in Figure 5.7 than in the right-of-center portion. Bauer (1938) discussed this photograph and illustrated by another similar photograph how such multiple paths could be by camera motion and lights. Zoege von Manteuffel (1938) indicated that no camera motion or lights were visible. However, with

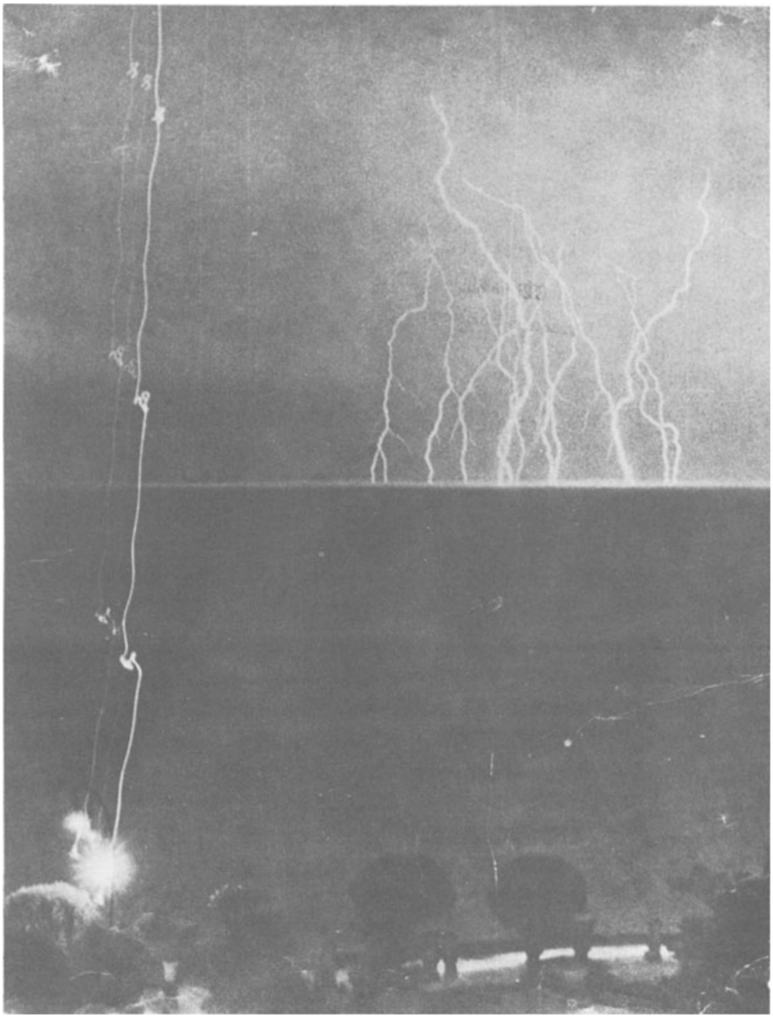

Figure 5.6. Still camera photograph of a multiple trace identified as having been caused by the path of a ball lightning. It is thought that camera motion was responsible for the multiple images. Reproduced with permission from *Ogonek*, Moscow, after I. Shagin, "Ball Lightning Photograph," *Ogonek*, **20,** 1960, p. 34, and reproduced by G. S. Teletov, "Sharovaya Molniia," *Priroda*, No. 9, 1966, p. 84; and English translation in G. S. Teletov, "Ball Lightning," *Foreign Science Bulletin*, **2,** No. 12, 1966, p. 53, and also in JPRS:39032, U.S. Dept. of Commerce, Washington, D.C., 1966.

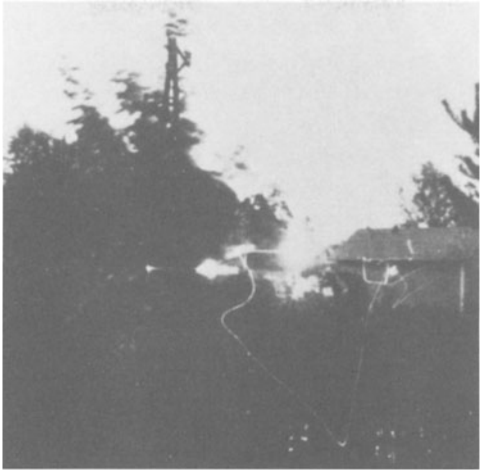

Figure 5.7. Still camera photograph showing a trace identified as having been caused by a ball lightning. A faint duplicate trace is also present and camera motion is thought responsible for the traces. Reproduced with permission from *Umschau*, Frankfurt, after P. Zoege von Manteuffel, "Eine Blitzaufnahme," *Umschau*, **42,** 1938, p. 587 and reproduced by C. Bauer, "Eine Blitzaufnahme," *Umschau*, **42,** 1938, p. 710.

the difficulty and confusion of the various claims, we cannot accept this photograph as representative of the ball lightning image and suspect camera motion as being responsible for the traces.

The photograph in Figure 5.8 by C. J. Young (1934) and reproduced by Dixon (1955) was easily recognized to have been due to an illuminated street lamp coupled with camera motion. An earlier suggestion that camera motion and street lamps could be easily coupled to form a multiple image similar to reported ball lightning photographs was made by Poulter (1935), and later by Poulter (1954a) and J. R. Scott (1955). The intentionally created multiple lightning image photograph by Poulter (1935) is shown in Figure 5.9.

The photograph shown in Figure 5.10 was made by H. Jack in 1955 and identified as that of a ball lightning. A faint secondary duplicate trace is observable to the upper right of the main trace. Because of the blurring of the main trace, it is thought that this figure was caused by camera motion. The photograph was apparently originally published by F. Wolf (1956a,b) and reproduced by Kapitza (1958) and Muhleisen (1972).

Bauer (1938) made the photograph of the nighttime street scene shown in Figure 5.11 by intentional camera motion. The main image

trace is a street lamp which appears as an intensity-modulated trace due to its 50-Hz ac electrical power. The photograph was originally used to illustrate that Figure 5.7 was erroneously identified as that of a ball lightning. The photograph also illustrates the difficulty in accepting a number of photographs identified as being of ball lightning. Israel (1960) also reproduced a photograph intentionally created by camera motion to illustrate that a photograph alone should not be considered sufficient to label an image as having been caused by a ball lightning.

It is clear that all of the photographs in this class of multiple traces may be as easily identified with camera motion and lamps as with a ball lightning trace. None of the reported multiple-trace ball lightning photographs are accompanied by definitive evidence that eliminates the camera motion proposal. It is the opinion of many investigators that none of these photographs can be unambiguously identified as being of ball lightning. All multiple-path ball lightning photographs must be evaluated with respect to camera motion. Thus, all such photographs showing multiple and/or duplicate traces must be suspect.

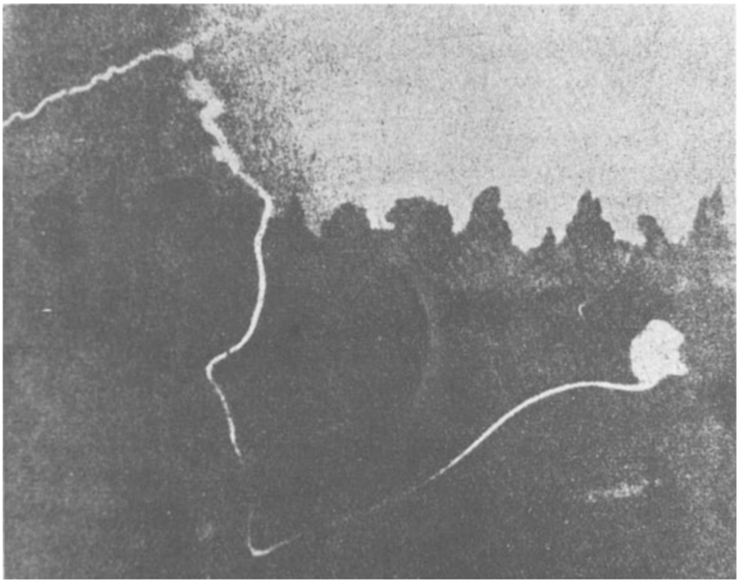

Figure 5.8. Still camera photograph identified as having been caused by camera motions. The image should be compared with the previous photographs of this section. Reproduced with permission from *Weather*, London. Originally published by C. J. Young, "Lightning Freaks at Peterborough," *The Peterborough Citizen*, London, 25 Sept. 1934 and reproduced by F. E. Dixon, "Photography and Ball Lightning," *Weather*, **10**, 1955, p. 98.

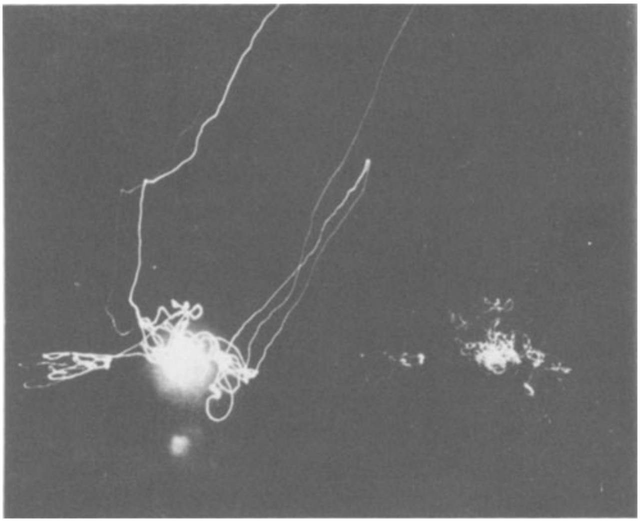

Figure 5.9. Still camera photograph of several street lamps intentionally created with camera motion. These traces illustrate the multiple trace characteristics and indicate the similarity to the previous photographs in this section. Reproduced from *Meteorological Magazine* with permission of the Controller of Her Britannic Majesty's Stationery Office, after R. M. Poulter, "Lightning Photographs," *Meteorol. Mag.*, **70,** 1935, p. 289, and reproduced by R. M. Poulter, "Photography and Ball Lightning," *Weather*, **9,** 1954, p. 121.

5.2.3. Class 3: Lightning Channel Decay

This class is characterized by the appearance of a separate, small disjointed segment of illumination near a normal linear lightning streak, apparently formed by the lightning and left as a single entity separate from the main discharge.

The concept that ball lightning is a result of a normal lightning discharge forming near the main channel is quite old. Since ball lightning appearances are predominantly associated with thunderstorm activity, it easily follows that ball lightning may be related to a lightning discharge. It was previously suggested by Meissner (1930) and Norinder (1939) among others that ball lightning forms at a region where the channel forms a severe turn or bend. An example of a similar characteristic associated with a ball lightning observation was reported by Hohr (1903).

A photograph illustrating this characteristic was published by Bauman (1937) and is reproduced here as Figure 5.12. An illuminated ball was reported to have appeared immediately after a lightning discharge. The ball was reported to have formed in the vicinity of the

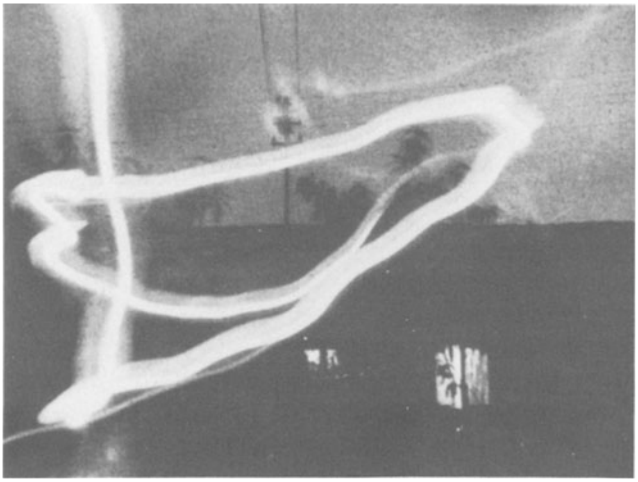

Figure 5.10. Still camera photograph taken during a lightning storm by H. Jack in 1955 and identified as being that of a ball lightning. A faint duplicate trace is observable in the upper right-hand portion of the figure. Reprinted with the permission of Springer-Verlag, New York, after F. Wolf, "Interessante Aufnahme eines Kugelblitzes," *Naturwiss.*, **43,** 1956, p. 415. Originally published by F. Wolf "Interessante Aufnahme eines Kugelblitzes," *Orion*, **4,** 1956, p. 589, and reproduced by P. L. Kaptiza, "Über die Natur des Kugelblitzes," *Phys. Blätt.*, **14,** 1958, p. 11, and R. Muhleisen, "Der Kugelblitz—ein Plasmazustand?," *Kosmos*, **68,** 1972, p. 159.

larger region at the lower end of the discharge channel. The resulting ball was not photographed alone.

The presence of an apparent luminous termination of a lightning channel may possibly be the result of the random motion of the channel in a small volume as the normal lightning discharge dissipates. This characteristic was discussed by Holtzer, Workman, and Snoddy (1938), and moving-film photographic evidence was recorded as shown in Figure 5.33. Such an occurrence could cause a persistent localized luminosity but it does not necessarily mean that a ball lightning is involved. The photographs in question also show the phenomenon at large distances, not near the observer as is common with ball lightning events.

A similar photograph of a normal lightning discharge but with a separate ball-like entity is shown in Figure 5.13 after Merhaut (1944). The small separate illuminated region is in the lower left of the photograph; an enlargement of the image is shown in Figure 5.14 and was also published by Merhaut (1944) and reproduced by Barry (1966). It was reported that the photograph was made during a thunderstorm, and the small region remained visible for a few seconds and had a fiery

Figure 5.11. Still camera photograph of a street scene made at night. The camera was intentionally moved to create the multiple trace characteristics. The main image trace is a street lamp which because of its 50-Hz ac electrical power, appears as an intensity-modulated trace. This photograph was used as the basis for questioning the validity of the photograph by Zoege von Manteuffel (1938) shown in Figure 5.7. Reproduced with the permission of *Umschau,* Frankfurt, after C. Bauer, "Eine Blitzaufnahme," *Umschau,* **42,** 1938, p. 710.

appearance similar to the photographs of Jensen (1933a,b) as shown in Figures 5.18 and 5.19. It was assumed that the small luminous region resulted from a bend in the lightning channel. The enlargement shows that the small luminous segment could be interpreted as a section of a lightning channel bend viewed end on.

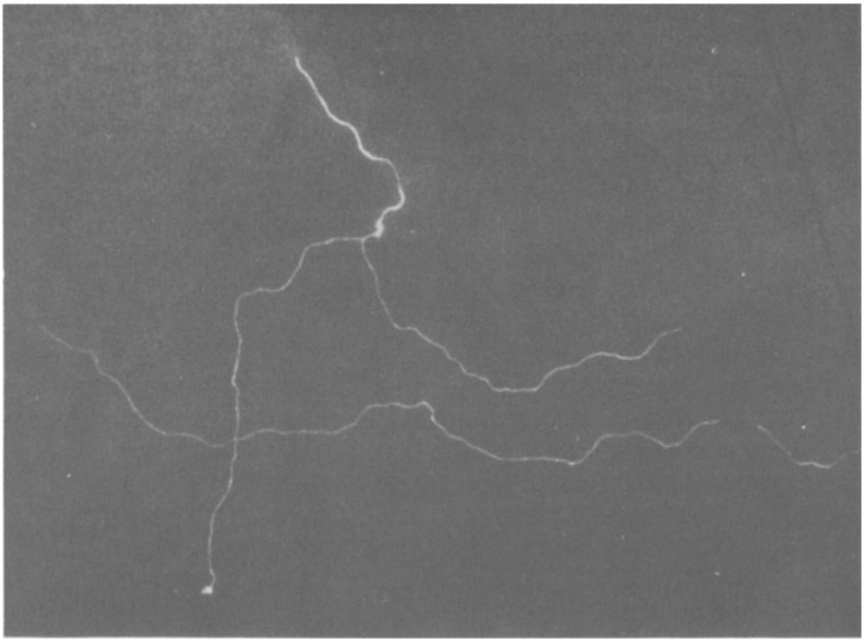

Figure 5.12. Still camera photograph of a lightning discharge with an apparent termination above ground, as shown by the trace in the lower left-hand section of the figure. The segment was reported to have developed into a ball lightning. Reprinted from G. Bauman, "Photographische Aufnahme einer Blitzkugel in Riga," *Meteorol. Zeit.*, **54,** 1937, p. 192.

Photographs of normal lightning that do not terminate at the ground have been published frequently but with no connection to a ball lightning appearance. It is easy to understand why the relationship with normal lightning evolved when photographs such as that by Norinder (1939) are studied. Norinder published a photograph similar to that of Figure 5.12, and another showing lightning terminating with an increased diameter at the end. It was reported that a lightning discharge of this type produced a residual ball lightning near the ground. The photograph by Norinder (1939) is reproduced in Figure 5.15.

The nighttime photographic records of the Prairie Meteorite Network of the Smithsonian Astrophysical Observatory, which was operated for about 10 years, were evaluated by Tompkins, Rodney, and Gooding (1975) and Tompkins and Rodney (1977). They evaluated about 12,000 photographs and found about 120,000 lightning stroke records. Twenty-four were interpreted to have been caused by either ball lightning (2) or bead lightning (22) events. McCrosky (1971) also reported an event that was interpreted as being bead lightning. Refer to Figures 2.12 and 2.13.

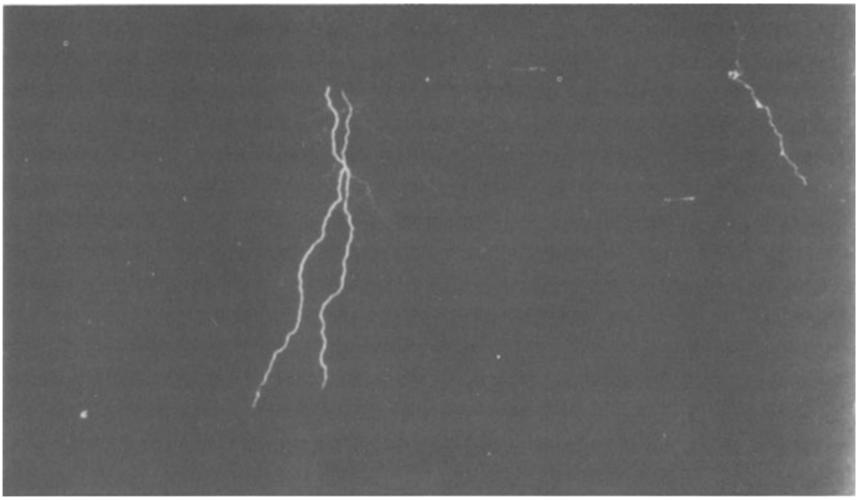

Figure 5.13. Still camera photograph made during a lightning storm. The singular image in the lower left-hand corner was reported to have transformed into a ball lightning phenomenon. Reproduced with permission from *Naturwissenschaften,* Springer-Verlag, New York, after O. Merhaut, "Eine Bermerkenswerte Blitzaufnahme," *Naturwiss.*, **32,** 1944, p. 212.

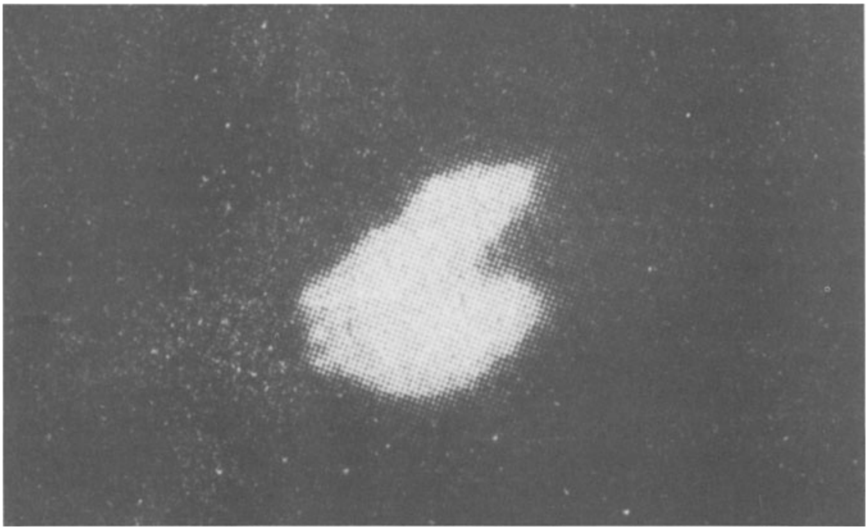

Figure 5.14. Enlargement of the singular trace shown in the lower left-hand corner of Figure 5.13, which was identified as that of a ball lightning. Reproduced with permission from *Naturwissenschaften,* Springer-Verlag, New York. Published by O. Merhaut, "Eine Bemerkenswerte Blitzaufnahme," *Naturwiss.,* **32,** 1944, p. 212.

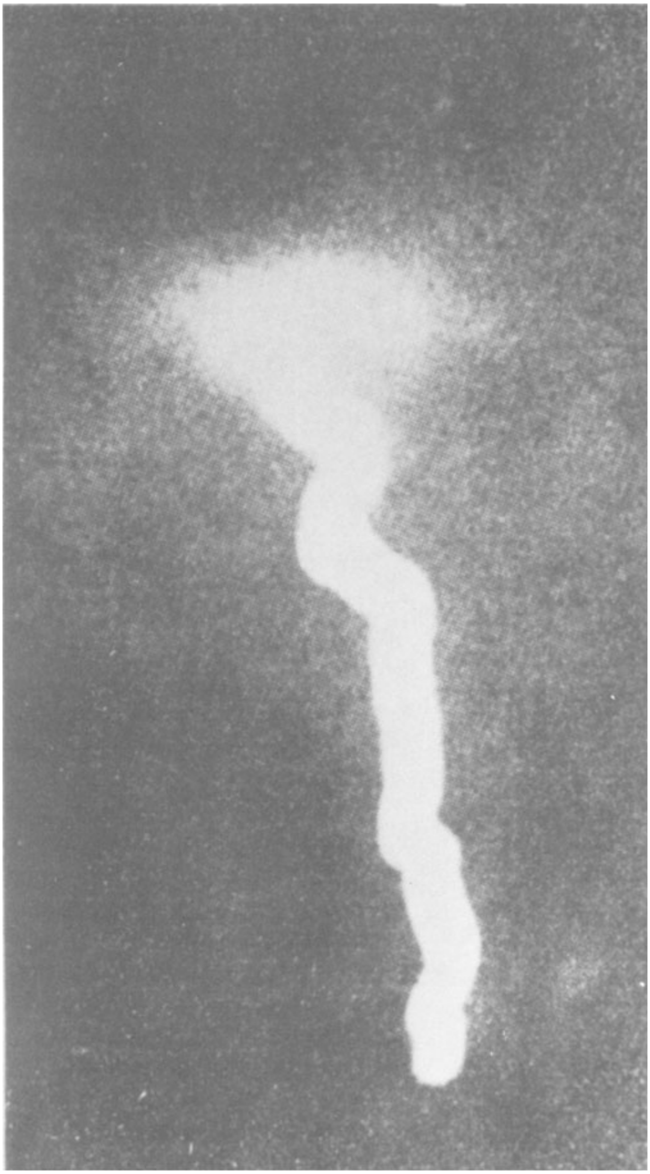

Figure 5.15. Still camera photograph of a lightning discharge from a cloud which reportedly terminated above ground and produced a ball lightning form from the termination point. Reproduced with permission from H. Norinder, "Om Blixtens Natur," *Kungliga Ventenskapssocietetens Arsbok,* **94,** 1939, p. 39.

The cameras were originally intended to study and record meteorite occurrences. They were directed to the night sky and operated automatically. The cameras were equipped with chopping shutters which exposed the film at a rate of 13.33 Hz so that the shutter was open for about 1/3 of the cycle. The aperture was open for 25 msec, closed for 38 msec, and required 6 msec to open or close. An illuminated or luminous object moving across the camera field of view would be recorded as a series of dotted or dashed traces. The photography of lightning channels was not unusual.

A typical lightning step leader would occur from cloud to ground in about 20 msec as measured by Krider, Weldman, and Noggle (1977). A dart leader would occur in only a few milliseconds. Consequently, a lightning discharge should be recorded within one shutter cycle. Longer events would indicate a persistent channel luminosity and could be interpreted as having been caused by ball or bead lightning.

One such recorded event was identified as having been caused by a ball lightning and is shown in Figure 5.16. Tompkins, Rodney, and Gooding (1975) and Tompkins and Rodney (1977) established the following conditions that should be fulfilled by a trace before it is identified as ball lightning: (1) The image must have a regular sequence indicative of the shutter control, and (2) the image must appear to exit nontangentially from the lightning channel. They used a statistical analysis on possible ball and bead lightning trace characteristics to determine randomness of periodicity. It was found that the traces were not random and that the dotted appearance was, in fact, caused by the chopped shutter. Additinally, the trace had a nontangential exit from the side of a lightning stroke.

The data further suggested a ball fall rate of 60–120 m per second. The image diameters were estimated from the range and image size and were of the order of meters. It was suggested that the use of large-scale automated night-sky cameras would constitute a definitive repeatable method of photographically observing ball lightning formation and events.

The occurrence of ball lightning was recognized as being somewhat rare. Based on the available data, the frequency of ball lightning in the midwest United States is once per 6×10^5 km^2 nights, which is equivalent to an event frequency of about 4×10^{-11} km^{-2} sec^{-1}.

This value may be compared to the relatively rare occurrence of intense lightning flashes as detected by satellite-borne instrumentation. Intense lightning strokes have been suggested as being responsible for the formation of ball lightning. Turman (1977) reported that such flashes are apparently over 100 times as intense as normal lightning

Figure 5.16. Still camera photograph which was part of the nighttime photographic records of the Prairie Meteorite Network of the Smithsonian Astrophysical Observatory. The camera was operated automatically with a chopped shutter which caused the aperture to open for 25 msec, close for 38 msec, and required 6 msec to open and close. A moving illuminated object would be recorded as a series of dashed lines. The analysis of the image and camera data suggested a single luminous object falling at a rate of 60–120 m sec^{-1} and having a diameter of 2–4 m. The broad vertical streak on the upper right was identified as a normal lightning stroke terminating above the ground. The discontinuous dotted path from the termination to the ground was identified as that of a ball lightning. Reprinted with permission of D. R. Tompkins from D. R. Tompkins, Jr., and P. F. Rodney, "Photographic Evidence of Ball and Bead Lightning," Terrence Corp., Refugio, Texas, unpublished, Oct. 1977. A similar photograph was distributed by D. R. Tompkins, Jr., P. F. Rodney, and R. Gooding, "Photographic Observations of Ball and Bead Lightning," University of Wyoming, Dept. of Physics and Astronomy, unpublished, 1975, and later by N. Charman, "Ball Lightning Photographed," *New Scientist*, **69**, 1976, p. 444, and by N. Charman, "Ball Lightning," *Phys. Rep.* **54** (4), 1979, p. 261.

and have a radiant energy in excess of 10^6 J. The event frequency was estimated as about 3×10^{-5} km^{-2} sec^{-1}. The probability of ball lightning formation, if related to the intense lightning flash, is rather low indeed.

Although a fairly large number of still photographs have been reported as being of ball lightning, few movie or videotaped films have been obtained. The only known videotaped film of an image identified as that of a ball lightning was reported by Eriksson (1977a). Thunderstorm lightning discharges were videotaped by Eriksson in the Transvall Highveld region of northern Africa. Single-frame images were made from the videotapes on a display monitor, and the resulting traces photographed with a still camera.

The time resolution of the video recording system was 20 msec—the single field sweep period. A single picture constituted a 20-msec integrated record. Sequential pictures related the recorded event at 20-msec intervals.

Eriksson published a sequence of eight pictures showing a faint downward leader and a bright return stroke. One of the pictures, frame 6, is reproduced here as Figure 5.17. A ball-like image appeared near the top of the main channel approximately 300 m above the ground. It appeared that the ball image occurred during the interstroke intervals, rather than during periods of main discharge illumination. It had a persistence of about 20–40 msec. The ball object had an apparent diameter of about 5 m. Image blooming was noted, however, so that the dimension is not definite. This dimension is similar to that reported by Jensen (1933a,b), which was also reported to have originated high above the ground. The Jensen photographs are shown in Figures 5.18 and 5.19.

Eriksson (1977a) commented that the ball image could not have resulted from an artifact of the optics as it was only observed for a short period and was observed only during the one lightning event. He also indicated that the identification as a ball lightning event was tentative and awaited corroboration by further evidence. However, the means of study—videotaping—is similar to that by Tompkins (1977)—remote photography, which was discussed earlier and in Chapter 2.

Such methods, remote automatic photography, movie film, and/or videotaping, represent the preferred means of ball lightning study.

It is extremely difficult to form a conclusive opinion regarding the validity of these previous photographs. One must to some extent rely upon the interpretations and scientific analysis. To that end, one must delay any firm pronouncement but remain open for further consider-

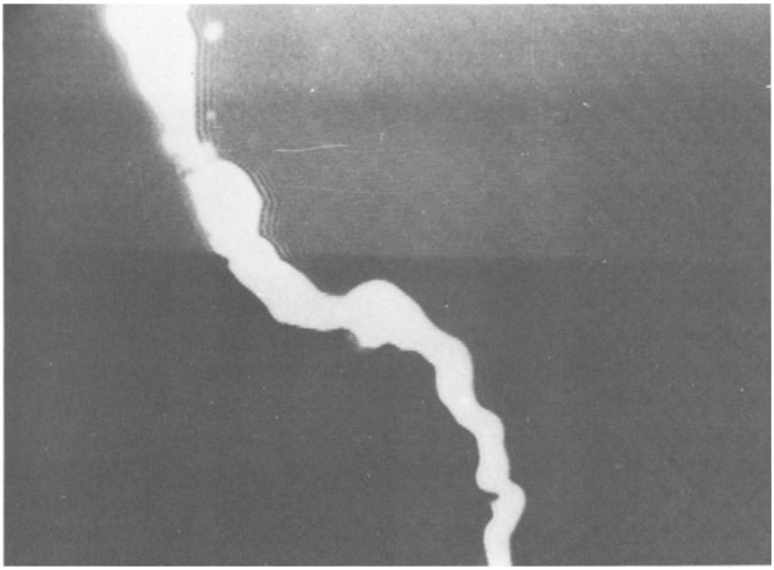

Figure 5.17. Single-frame photograph from a videotaped series showing a luminous ball image which appeared at the top of a lightning stroke. The frame duration was 20 msec and the ball duration was about 20–40 msec. The ball occurred about 300 m above the ground and had a diameter of less than 5 m. The photograph was reproduced with permission of A. J. Eriksson and *Nature,* London, from A. J. Eriksson, "Video-Tape Recording of a Possible Ball Lightning Event," *Nature,* **268,** 1977, p. 35, and was reprinted later by N. Charman, "Ball Lightning," *Phys. Rep.,* **54** (4), 1979, p. 261.

ations. The figures do have the interrelating and common characteristics suggesting ball lightning formation from a normal lightning discharge. The photograph by Tompkins and Rodney (1977) is only one of several that were uncovered during the analysis of thousands of automatically shuttered photographs. This is perhaps the most intriguing photograph presently available. One may suggest that, based upon the available evidence and its interpretation, the Tompkins and Rodney (1977) photograph may represent one of the few valid ball lightning photographs in existence.

5.2.4. Class 4: Pyrotechnic Appearance

This class is characterized by an apparently slightly elongated illuminated globe, apparently in upward motion, with streamers of residual illuminated material forming a trail behind the single main

body. The appearance is similar to that of a single Roman candle ball in slow motion.

The ball lightning is described as having the appearance of a pyrotechnic display. It is often reported as a burning ball emitting flames and remnants of an apparent combustion process. The appearance has the flame characteristics of color and structure, except that the motion is subdued. A red-yellow color is common with a diameter of 50–100 cm and occasionally even larger. The phenomenon has occurred singly or as one of a group of similar objects. This type of ball lightning appearance is supported by numerous observational reports as well as a number of photographs.

A number of observational reports that describe a fiery ball lightning with residual material being lost during its motion include Anon (1886a, 1890k, 1964b), C. Hare (1878), Hunneman (1937), and W. F. Smith (1880). Some other reports complicate the evaluations. Scott (1878b) for example, describes a green St. Elmo's Fire which left residual green luminous matter as it rose above a tree.

Many reports describe the ball lightning as resembling a ball of fire with flamelike structures and protrusions. As such, under some conditions these flame structures could resemble residual material being ejected during the course of the phenomenon. A number of reports that describe a fiery ball lightning include Boll (1918), Brzak (1892), Budde (1920), Clavel (1901), Cocking (1884), Haag (1914), Hofman (1919), Moon (1925), Mott (1880), Palazzo (1903), Rahir (1901), Roth (1889), W. F. Smith (1880), W. G. Smith (1884), Stunder (1888), Violle (1901a), A. Wagner (1939), Wainhouse and Pitcairn (1773), Weber (1911), and Zapletal (1970). One must be careful to avoid confusion; Schlobohm (1961), for example, describes a fiery phenomenon which occurred on the ground near the observer and was probably a St. Elmo's Fire.

The fiery or pyrotechnic ball lightning photographs have met with much discussion and speculation concerning their origin. The most reproduced and discused set of photographs was originally published by Jensen (1933a,b). The photographs were obtained during a thunderstorm in Nebraska, USA. The storm clouds were of the nimbus type preceded by a cooler air mass. Normal lightning from cloud to ground occurred repeatedly. The ball lightning incident occurred during the thunder and lightning storm when a lavender-colored mass was observed to descend slowly from a cloud. The structure of the mass was described as shapeless but somewhat globular and having a pyrotechnic resemblance. A few of the structures fell onto nearby power lines, rolled

along the wires for 100 feet or more, and fell to the ground with an explosive decay.

The photograph shown in Figure 5.18 is from Jensen (1933a) and that in Figure 5.19 from Jensen (1933b). These two figures represent just two examples of the many photographs published by Jensen. These photographs were discussed by Singer (1971), who dismissed the rumor that a Roman candle firework display was responsible for the observations. The original photographs and negatives were evaluated by Salanave (1965), who concluded that these images were not at all similar to those of a fireworks display. Berger (1973) and Singer (1971) also

Figure 5.18. Still camera photograph made during a thunderstorm and showing several single images identified as ball lightnings. A number of such photographs were originally published, all showing such phenomena. The display was witnessed by a respected scientist. Reproduced with permission from J. C. Jensen, "Ball Lightning," *Scientific Monthly*, **37**, 1933, p. 190, and reproduced by N. V. Kolobokov, *Grozy i Shkvaly*, Gos. Izdat. Tekh.-Teor. Lit., Moscow, 1951; by F. W. Lane, *The Elements Rage*, Chilton, New York, 1965; by R. A. Leonov, *The Riddle of Ball Lightning*, Izd.-Vo., Nauka, Moscow, 1965, and by S. Singer, *The Nature of Ball Lightning*, Plenum Press, New York, 1971.

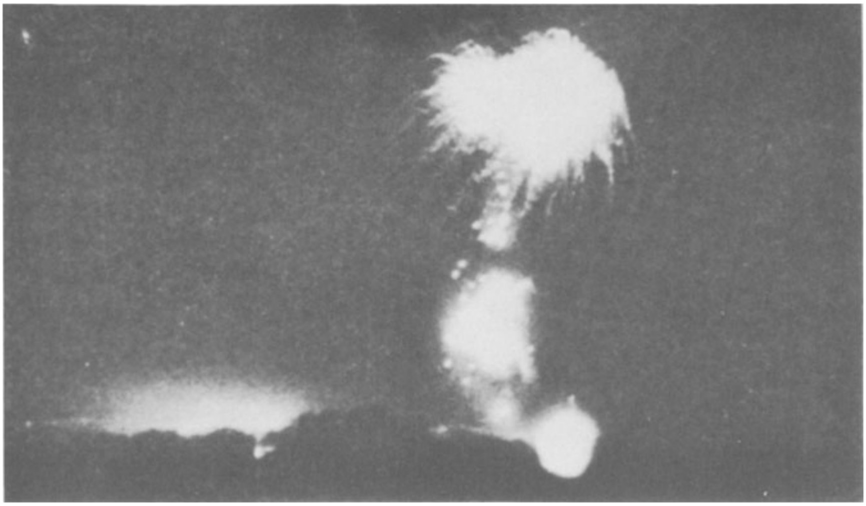

Figure 5.19. Still camera photograph made during a thunderstorm showing several singular images identified as being ball lightning. Refer to Figure 5.18. Reproduced with permission from J. C. Jensen, "Ball Lightning," *Physics,* **4,** 1933, p. 372, and reproduced by N. V. Kolobokov, *Grozy i Shkvaly,* Gos. Izdat. Tekh.-Teor. Lit., Moscow, 1951; by F. W. Lane, *The Elements Rage,* Chilton, New York, 1965; by R. A. Leonov, *The Riddle of Ball Lighnting,* Izd.-Vo. Nauka, Moscow, 1965; by G. S. Teletov, "Ball Lightning," *Priroda,* No. 9, 1966, p. 84, English translation in *Foreign Science Bull.,* **2,** No. 12, 1966, p. 53 and also in JPRS 39032, U.S. Dept. of Commerce, Washington, D.C., 1966; by S. Singer, *The Nature of Ball Lightning,* Plenum Press, New York, 1971; and by B. H. Bailey, "Ball Lightning," *Weatherwise,* **30** (3), 1977, p. 99.

raised the question of Jensen being misled by fireworks. He cited an unpublished investigation of the incident by H. Norinder. The appearance of the images was reportedly closely duplicated by Roman candles. Solanave was reported to have accepted the similarity.

The actual object of the Jensen photographs, whether ball lightning or fireworks display, may never be settled. However, observations of such ball-of-fire structures in tornadoes have been reported by Vonnegut and Weyer (1965) and by Vaughan and Vonnegut (1976). Merhaut (1944) also indicated that his observation was similar to that of Jensen (1933b) as shown in Figure 5.13.

A photograph that shows the ball lightning with residual material apparently being evolved as the ball rose is shown in Figure 5.20 after Kuhn (1951). An enlargement of the singular object in Figure 5.20 was also published by Kuhn (1951). The enlargement more clearly shows streamerlike material apparently being ejected from the main ball

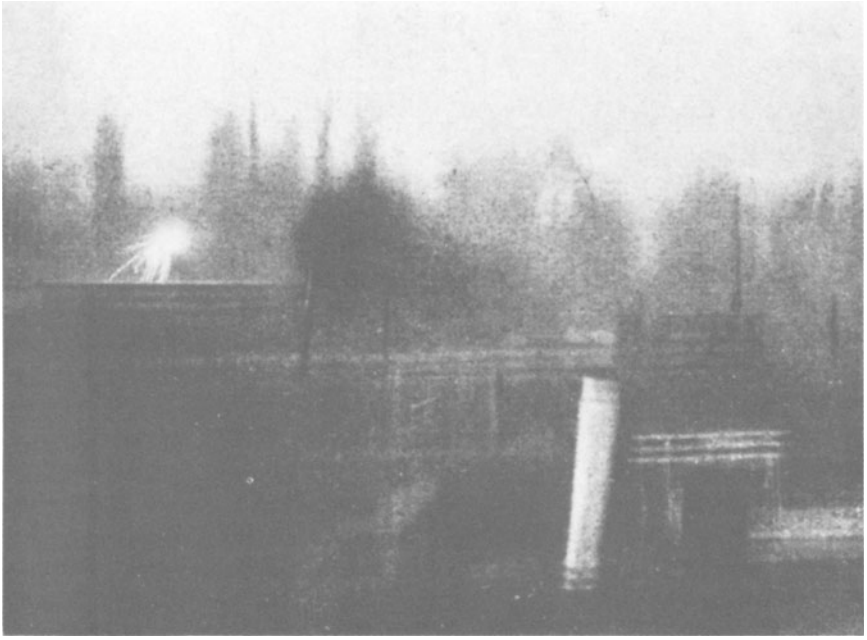

Figure 5.20. Still camera photograph of an object identified as a ball lightning. The phenomenon was reported to have risen from behind a structure and appeared to emit a luminous residue as it passed. Reproduced with permission from *Naturwissenschaften*, Springer-Verlag, New York, after E. Kuhn, "Ein Kugelblitz auf einer Moment-Aufnahme?," *Naturwiss.*, **38,** 1951, p. 518, and reproduced by E. von Kilinski, *Lehrbuch der Luftelektrizität,* Akademische Verlagsgesellschaft, Geest & Portig, K.-G., Leipzig, 1958; and by N. Charman, "The Enigma of Ball Lightning," *New Scientist,* **56,** 1972, p. 632.

lightning, which was observed to rise from the ground. A number of other reports, such as Anon (1890k, 1919a,b), Hunneman (1937), Jaeger (1961), Lancaster (1905), and Mott (1880), discuss ball lightning phenomena with rays or streamers.

The photograph by Kuhn (1951) was also discussed by Berger (1973). Berger reported that a Professor Schwenkhagen visited the site of the observation by Kuhn and concluded that a storm had caused a short-circuit discharge on a power line. He suggested that the resulting spraying molten metallic drops were mistaken for a ball lightning. Lightning strikes to the tower were not mentioned and investigation of the tower was not conducted. The upward motion of a mass of molten metal is not considered too probable.

A similar but earlier drawing of a ball lightning phenomenon with streamerlike ejected material was published by von Haidinger (1868a).

The drawing is reproduced here in Figure 5.21 and is easily recognized to be quite similar to that in Figure 5.20. It was described as leaving residual material as it rose past the observer.

Several other drawings of fiery and streamer-type ball lightnings have been published. Bonacina (1946) discussed a ball lightning event in 1638 which caused much destruction. Flammarion (1874) and later Leonov (1965) included a drawing of a ball lightning on the floor of a barn—see Figure 1.2. Viemeister (1961) and later Powell and Finkelstein (1969) reproduced an earlier drawing by Figuier (1870) and Figuier (1884) of the ball lightning event that caused the death of Dr. G. W. Richman in Petersburg in 1753. Refer to the discussion in Chapter 7, Section 7.2, and Figure 7.1.

5.2.5. Class 5: Stationary Image

This class is characterized by a singular quasispherical image hovering above the ground apparently without motion.

One of the earliest broad evaluations of the ball lightning phenomenon was by Brand (1923, 1971). Brand collected several hundred reports on ball lightning observations and made a quasistatistical study

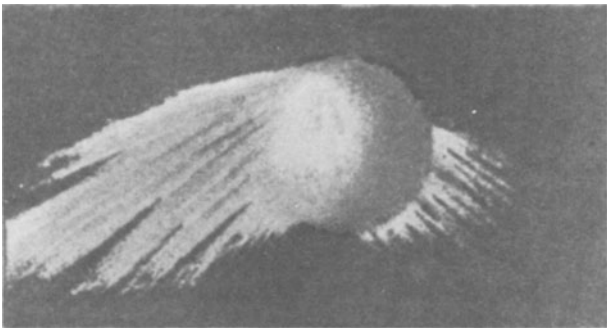

Figure 5.21. A drawing illlustrating an object identified as a ball lightning which was observed outside of a window. Residue material was observed to have been ejected during its passage. Reproduced with permission from *Naturwissenshaften,* Springer-Verlag, New York. Originally published by W. Von Haidinger, "Elektrische Meteore am 20 October 1868 in Wien Beobachtet," *Sitzber. Math.-Naturwiss. Kgl. Akad. Weiss, Wien, II,* **58,** 1968a, p. 761 and reproduced by S. A. Arrhenius, *Lehrbuch der Kosmischen Physik I,* S. Hirzel, Leipzig, 1903; by F. Wolf, "Das Gewitter and seine Entladungsformen II. Teil: Kugelblitze and Perlschnurblitze," *Naturwiss.,* **31,** 1943, p. 215; by C. Bendicks, "Theory of the Lightning-Balls and its Application to the Atmospheric Phenomenon called Flying Saucers," *Arkiv foer Geofysik,* **2,** 1954, p. 1; and by S. Singer, *The Nature of Ball Lightning,* Plenum Press, New York, 1971.

of those reports. He indicated that, at that time, no known photographs of the natural ball lightning phenomenon existed. Brand also reproduced two photographs of a spherical luminosity caused by the shorting of a direct current electrical generator. The two photographs are shown in Figure 5.22 and 5.23 and have been included here rather than in Class 8 since the phenomena occurred in the atmosphere. In the latter photograph, the ball had risen above the larger glowing region.

It is assumed that the manually caused discharge, perhaps in the presence of water vapor, led to the formation of the ball-lightning-like phenomenon. The details of these phenomena are quite difficult to distinguish, and little detail and few specific characteristics were reported by Brand. The phenomena were reddish in color, could be formed repeatedly, and lasted for a few seconds. The output potential of the direct current electrical generator was 10^7 W at 12 kV. If the shorting period was about 1 msec, then the energy available to the

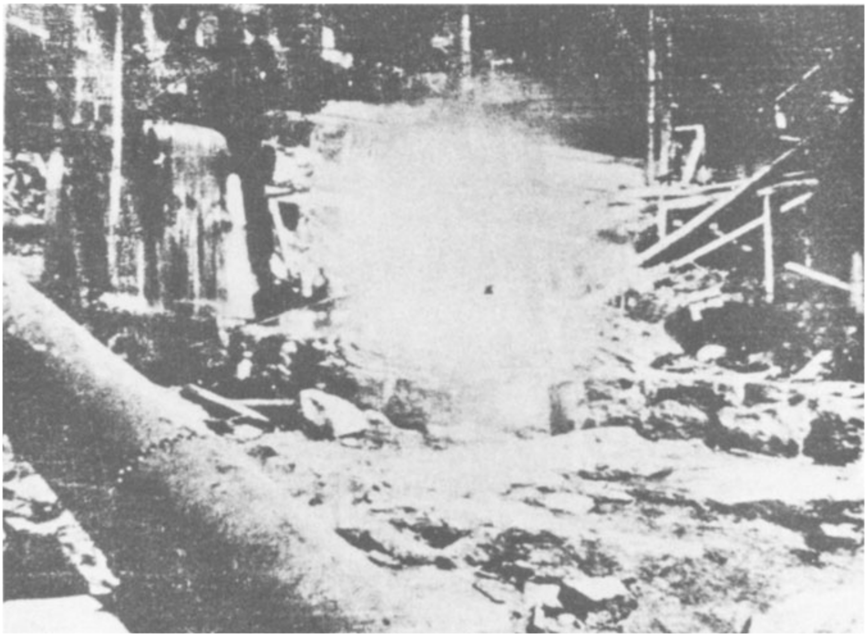

Figure 5.22. Still camera photograph of an illuminated globe produced by the electrical shorting of the terminals of a generator near a waterfall. The photographs were originally taken by A. Nielson. Reproduced with permission of Akademische Verlagsgesellschaft, Geest and Portig, K.-G., Leipzig, after W. Brand, *Der Kugelblitz*, Probleme der Kosmischen Physik, II/III, H. Grand, Hamburg, 1923, and reproduced in a later translation, *Ball Lightning*, by W. Brand, NASA Technical Translation, F-13228, 1971.

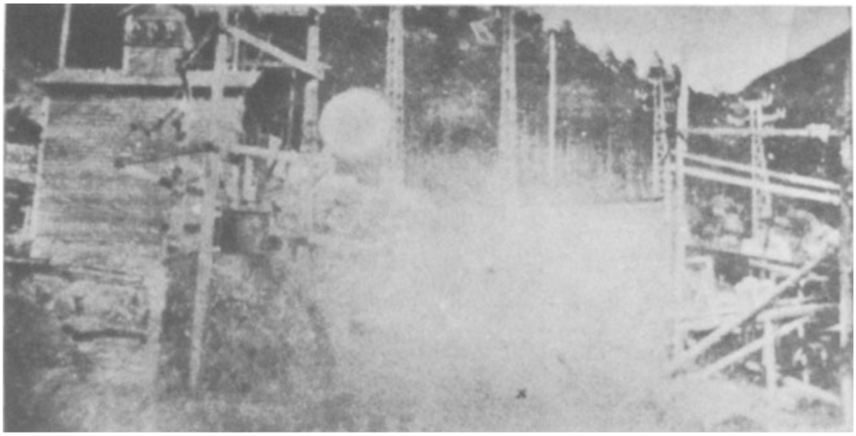

Figure 5.23. Another still camera photograph of an illuminated region produced by the electrical shorting of the terminals of a generator. Refer to Figure 5.22. Reproduced with permission of Akademische Verlagsgesellschaft, Geest and Portig K.-G., Leipzig, after W. Brand, *Der Kugelblitz*, Probleme der Kosmischen Physik, II/III, H. Grand, Hamburg, 1923, and reproduced in a later translation, *Ball Lightning*, by W. Brand, NASA Technical Translation, F-13228, 1971.

phenomenon depicted in Figures 5.22 and 5.23 would have been about 10^4 J. Norinder (1965) and Singer (1971) also commented on these photographs. Refer to Chapter 7, Section 7.4, for a more complete discussion of this event.

A better-defined photograph of an image presented as being that of a ball lightning was published by Norinder (1939) and is reproduced here as Figure 5.24. It was also reproduced by Norinder (1965) and Singer (1971). The photograph was identified as that of a ball lightning as it reportedly moved past a building near the observers. A second ball lightning was also observed but not photographed. The diameter of the ball lightning was reported to have been about 30 cm.

A photograph of a stationary illuminated image was published by Charman (1976) and is shown in Figure 5.25. A similar drawing was published by Geist (1949) and is shown in Figure 5.26. Both show an apparently motionless image suspended above the ground. Both were supported by observational information. However, neither of these photographs provides much information to the investigator or furthers the definitive knowledge of the ball lightning phenomena. The three earlier figures, on the other hand, are more substantiative and provide definitive information. Most importantly, it has been well established that a ball-lightning-like phenomenon can be produced by electrome-

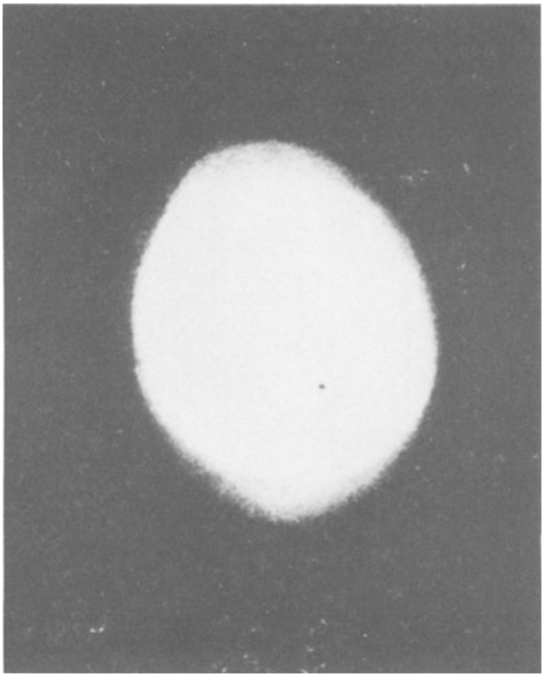

Figure 5.24. Still camera photograph identified as that of a ball lightning obtained during a lightning storm by H. Schneidermann in 1935. Reprinted from H. Norinder, "Om Blixtens Natur," *Kungliga Ventenskapssocietetens Arsbok,* **94,** 1939, p. 39, and reproduced by H. Norinder, "Comments," in *Problems of Atmospheric and Space Electricity,* S. C. Coroniti, Editor, Elsevier, Amsterdam, 1965, p. 455; by S. Singer, *The Nature of Ball Lightning,* Plenum Press, New York, 1971; and by B. H. Bailey, "Ball Lightning," *Weatherwise,* **30** (3), 1977, p. 99.

chanical means. This provides impetus for experimental investigations and basis for theoretical evaluations. Refer to Chapter 7, Section 7.4.

Occasionally, a photograph identified as being of ball lightning will evoke critical response. The photograph shown in Figure 5.27 is an example. Prochnow (1928) apparently published the photograph originally made by a Judge Hannsperger in the book *Erdball und Weltall* and later in Prochnow (1930a), in response to criticism. Walter (1929) published a discussion of the book and a number of the photographs. He suggested that the photograph may have been a double exposure of house lights and a street lamp, and might have been caused by camera motion. A similar criticism was apparently published by F. Linke in Frankfurt according to Prochnow (1930a). The Linke report has been unavailable to this author.

Figure 5.25. Still camera photograph by M. R. Lyons of a single illuminated object suspended in the air above a garden. The image was identified as that of a ball lightning. Details of the observation are scarce. Reproduced with permission from *New Scientist,* the Weekly Review of Science and Technology, where the photograph first appeared. Reprinted from N. Charman, "Ball Lightning Photographed," *New Scientist,* **69,** 1976, p. 444.

The discussion of Prochnow (1930a,b) regarding the facts surrounding the photograph were somewhat vague. The photograph was self-developed and the condition of the camera and the actual exposure were reconstructed from memory. A ball lightning was not observed by the photographer and he was surprised to find the images on the film. The photograph is highly questionable.

5.2.6. Class 6: Uninterrupted Singular Trace

This class is characterized by a well-defined singular trace of a constantly illuminated object during motion over an apparently random path.

It is interesting that many of the so-called photographs of ball lightning have been made by accident. That is, during a still camera time-exposure photograph of a thunderstorm, an unwitnessed luminous phenomenon left an unexpected trace on the film. The resulting trace

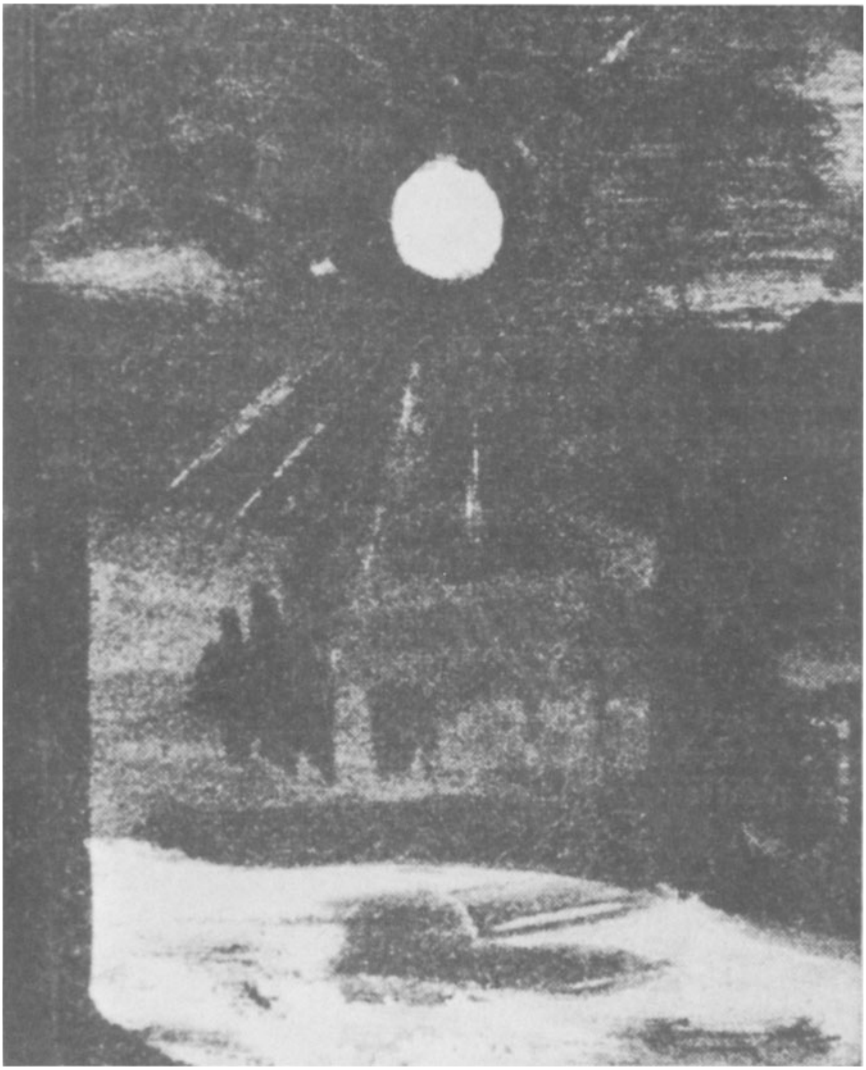

Figure 5.26. Drawing showing a singular illuminated object reported to be a ball lightning. Details of the observation were reported. Reproduced with permission from *Umschau*, Frankfurt. Reprinted from F. Geist, "Eine Kugelblitzbeobachtung in Oberbayern," *Umschau*, **49**, 1949, p. 255.

is then identified as having been caused by a ball lightning.

The photograph shown in Figure 5.28 was published by B. W. Cartwright (1938) and is typical of the results of an accidentally made ball lightning trace. It was originally reported as a lightning path, and

later reproduced and discussed by Holtzer and Workman (1939). They pointed out the apparent ribbon or tubular structure of the lightning channel. Camera motion was probably not involved as the background objects are not blurred. The trace in Figure 5.28 is similar to other lightning photographs but differs in that the apparent path was horizontal and indicates a structure. The identification of this photo-

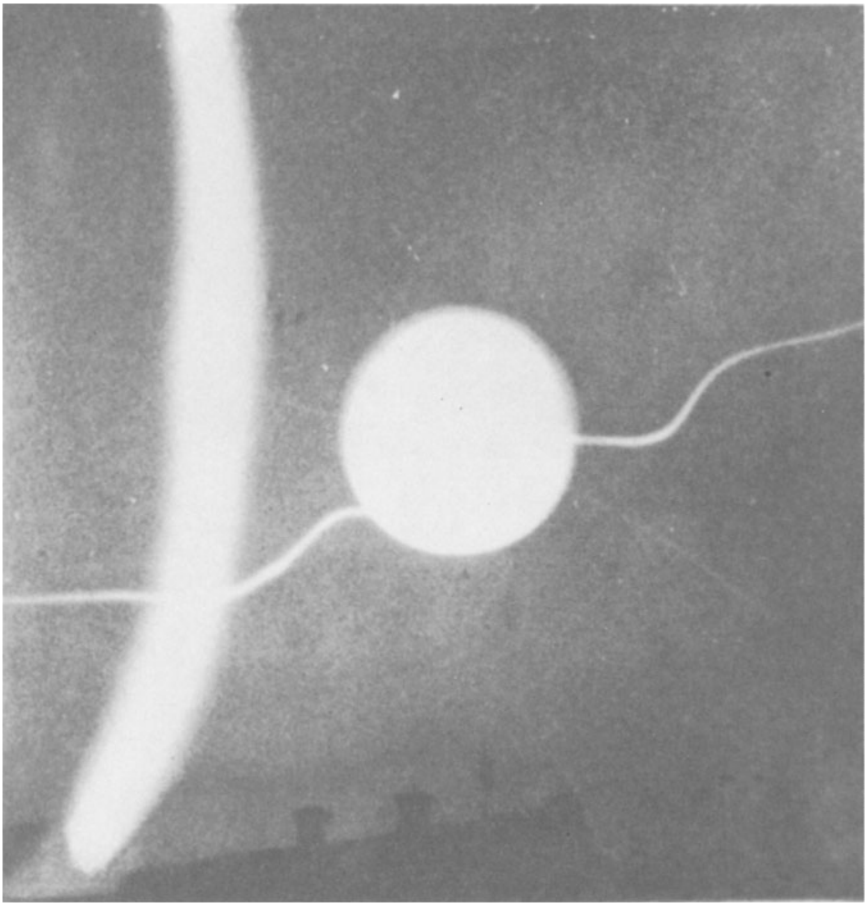

Figure 5.27. Still camera photograph taken during a thunderstorm and reportedly showing a motionless image of a ball lightning and possibly the traces of several others at various distances from the camera. The validity was questioned by Walter (1929), who suggested a double exposure. Camera motion, street lamps, and a house light were suspected as being responsible. Reproduced from O. Prochnow, "Zur Blitzforschung," *Physik. Zeit.*, **31,** 1930, p. 335. The photograph was apparently originally published by O. Prochnow, *Erdball und Weltall,* H. Bermuhler, Berlin, 1928.

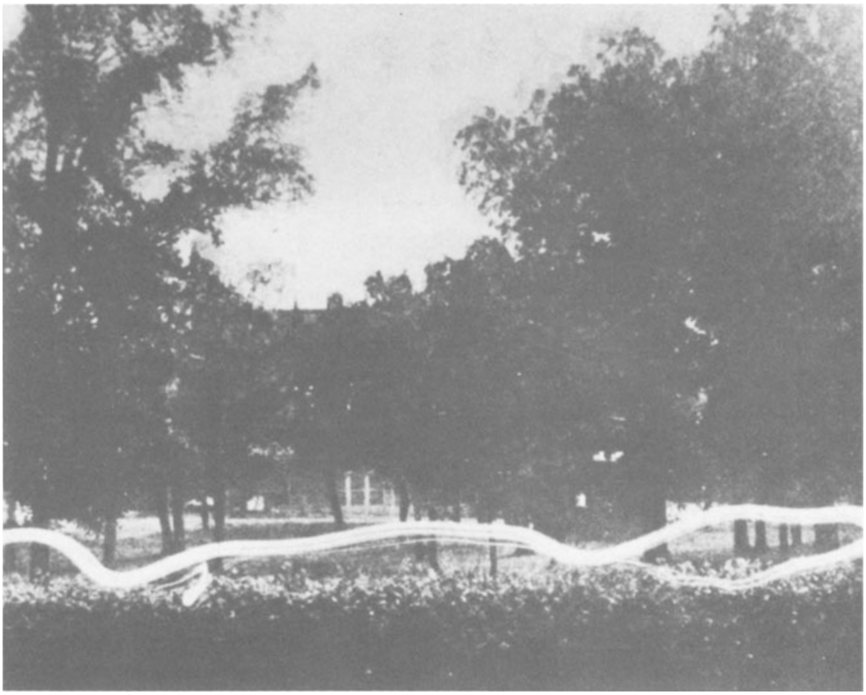

Figure 5.28. Still camera photograph made during a thunderstorm showing the path of an illuminated object. The path was initially identified as having been caused by a horizontal lightning discharge, and later as a ball lightning trace. No ball lightning observation was originally reported. Reproduced with permission from the *Journal of Applied Physics* and Dr. R. E. Holtzer. Originally published by B. W. Cartwright, "Lightning," *Life Magazine,* **3,** 1938, p. 77 and reproduced by R. E. Holtzer and E. H. Workman, "Photographs of Unusual Discharges Occurring during Thunderstorms," *J. Appl. Phys.*, **10,** 1939, p. 659; by G. S. Teletov, "Sharovaya Molniia," *Priroda,* No. 9, 1966, p. 84, English translation in JPRS 39032, U.S. Dept. of Commerce, Washington, D.C., 1966, and in *Foreign Science Bull.,* **2,** No. 12, 1966, p. 53.

graph as being that of a ball lightning was apparently made by Teletov (1966a–c), who also reproduced the photograph.

It has been observed that lightning may occur in a horizontal tubular form as indicated by Terada (1931) in relation to luminous phenomena observed during earthquakes. Pierce and Carlstead (1966) also reported a first-person observation of an apparently long-lived, horizontal, tubular lightning segment. The segment was bright blue in color, opaque rather than translucent, about 8 m (25 ft) in length, and 40 cm (15 in.) in diameter. The tubular appearance, of course, may be the result of a rapidly moving leader stroke in a narrow limited region,

as verified by the fast camera studies of Holtzer, Workman, and Snoddy (1938). Refer to Figure 5.33 and Figure 5.34.

A similar photograph of the quasihorizontal path made by a luminous object is shown in Figure 5.29. The photograph was originally published by Petersen (1954a,b) and reproduced by Muller-Hillebrand (1963) and Singer (1971). The photograph was taken by M. Bird in Odense. Based upon notes and recollections of a witness, the object was observed to pass slowly across their view. The ball diameter was estimated to be about 5 cm. The ball ended by traveling down a chimney and exploding in the fireplace.

The photographic also elicited much discussion, mainly due to the obvious camera motion present, which was reported by Petersen. Poulter (1954a) referred to the Petersen photograph as a good example of an image caused by camera motion. Poulter repeated earlier arguments

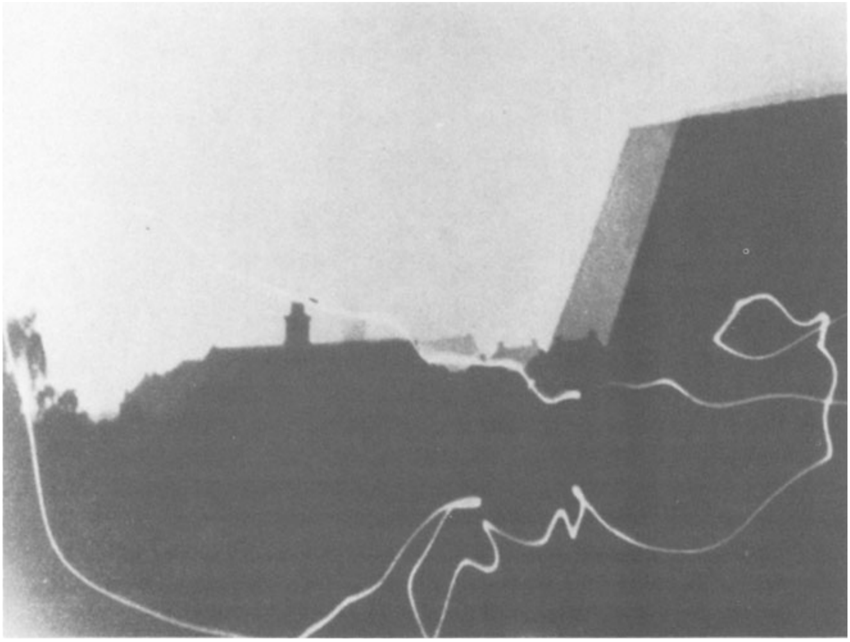

Figure 5.29. Still camera photograph by M. Bird showing the trace of an illuminated source which was identified as a ball lightning. The obvious camera motion has caused the photograph's validity to be questioned by Poulter (1954). Reproduced with permission from *Geophysica,* Helsinki. Originally published by H. Petersen, "Ball Lightning," *Weather,* **9,** 1954, p. 73, and reproduced by H. Petersen, "Ball Lightning," *Geophysica,* **5** (1), 1954, p. 49; by D. Muller-Hillebrand, "Zur Frage des Kugelblitzes," *Elektrie,* **17** (7), 1963, p. 211; and by S. Singer, *The Nature of Ball Lightning,* Plenum Press, New York, 1971.

from Poulter (1935) about the difficulty of interpreting photographs of lightning discharges. He also published a photograph of a so-called lightning trace which was made by time exposure of a street lamp by moving the camera. Dixon (1955) also interpreted the photograph as due to camera motion, pointing out the similarity with an earlier photograph by C. J. Young (1934) shown in Figure 5.8. J. E. Taylor (1954) and Poulter (1954b) also found fault with the explanation of the circumstances of the photograph by Petersen (1954c), who maintained that it was made during the day. It was recognized that, although it would have been difficult, it would not have been impossible to take such a photograph near dusk.

The photograph may have similarities to those produced by camera motion but differs in that supportive reports were available. In general, few ball lightning photographs are accompanied by supportive eyewitness reports; but the Petersen photograph did have eyewitnesses. Based upon the evidence available, the identification of the photograph must remain questionable but cannot be termed erroneous at this time.

Davidov (1958) published the remarkable photograph shown in Figure 5.30. It was later reproduced by Leonov (1965) and Singer (1971) and discussed at some length. Again this photograph was made accidentally by time exposure and not witnessed by the photographer. Davidov interpreted the smooth unbroken lines as having been caused by a ball lightning. The trace ended at the edge of a window as shown near the right edge of Figure 5.30.

Investigation of the window by Davidov indicated traces of soot about 1 cm in length on the undamaged window. A 3–4-cm carbonized section of the wood casement and a small section of pliable putty were reportedly found, possibly indicating the point of contact. A sootlike residue after a ball lightning event has been reported previously, for example, by Webber (1907).

The Davidov photograph has not been the center of controversy or discussions regarding its validity as was the case with the previous photographs. This may have been due to the comments of Stekol'nikov (1955), which appeared on the same page as the article by Davidov. Stekol'nikov suggested that the photographic trace could have been caused by several means, even natural lightning. The Davidov photograph does resemble that of natural lightning published by Holtzer and Workman (1939) which is reproduced in Figure 5.35. The photographs shown in Figures 5.30 and 5.29 should both be compared to those of natural lightning shown in Figures 5.33 and 5.34. The Davidov photograph must remain questionable.

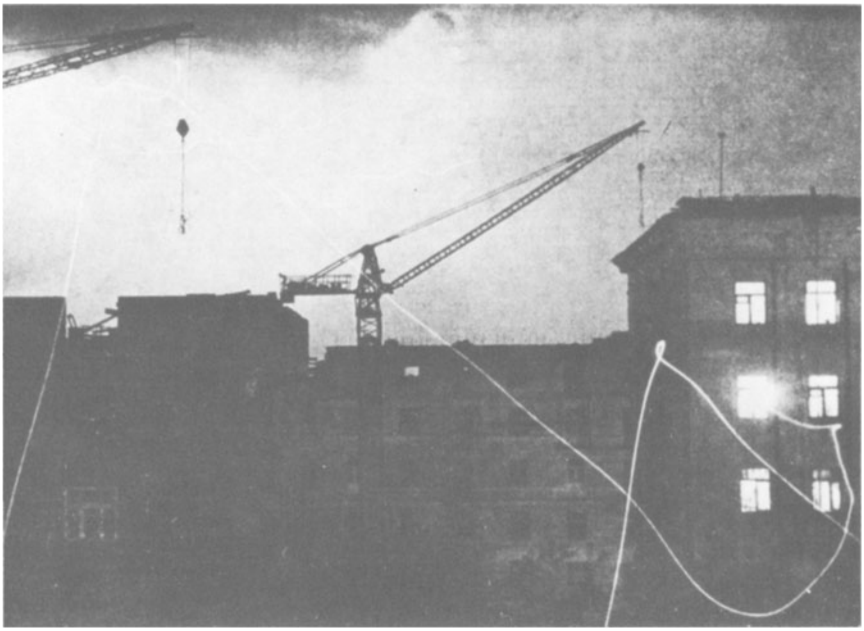

Figure 5.30. Still camera photograph made during a storm showing the singular trace of an unobserved object later identified as a ball lightning. A sootlike residue was found at the window where the object terminated its path. Reproduced with permission from *Priroda*, Moscow, after B. Davidov, "Redkaia Fotografiia Sharovi Molnii," *Priroda*, **47,** No. 1, 1958, p. 96, and reproduced by R. A. Leonov, *The Riddle of Ball Lightning*, Izd. Nauka, Moscow, 1965; by S. Singer, *The Nature of Ball Lightning*, Plenum Press, New York, 1971; and by B. H. Bailey, "Ball Lightning," *Weatherwise*, **30** (3), 1977, p. 99.

Dmitriev (1971) reproduced a photograph originally published by Daerdaeevskii (1957), which was also identified as that of a ball lightning. The photograph was made by Ya. Duschelivich, a scientific associate of the Bucharest Aerological Observatory. The ball lightning appeared during a thunderstorm at the Predial Mountain pass in the Carpathians and was reported to have been observed for a period of time during the storm. The photograph is reproduced here as Figure 5.31.

Dmitriev, Deryugin, and Kalinkevich (1973) made an analysis of the photograph and the observational data. They concluded that the object had a diameter of 6–8 cm and had an oscillating luminosity with a frequency of 3–5 Hz. The oscillating behavior was related to a 20%–30% growth in the ball diameter and an associated decrease in the total luminosity. The object appeared to have been influenced by

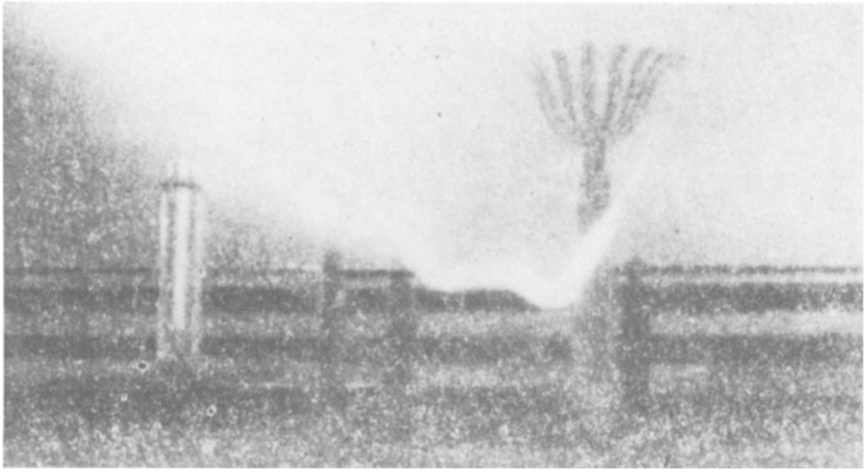

Figure 5.31. Still camera photograph by Ya. Dushelivich of a luminous ball lightning object which was observed during a thunderstorm in a mountain pass in the Carpathians. The object was reported to have had a diameter of 6–8 cm and an oscillating luminosity. Reproduced with permission from *Priroda,* Moscow, after M. T. Dmitriev, "Sharovoy Molnii: Novyye Nablyudeniya i Novyye Gipotezy," *Priroda,* No. 6, 1971, p. 50, English translation, "Ball Lightning: New Observations and New Hypotheses," NASA Technical Translation, F-13931, Sept. 1971. Originally published by B. L. Daerdaeevskii, "Redkii Snimok Molnii," *Priroda,* No. 4, 1957, p. 113.

metallic objects nearby, possibly by related electric and/or magnetic field gradients. The ball lightning was also reported to have decayed gradually over a distance of a few diameters. As it did so, it shed a shower of sparks, apparently like the phenomenon reported by Kuhn (1951).

The identification of a trace as that of a ball lightning is difficult without supportive information. One example is the photograph published by Rutgers (1958) and shown in Figure 5.32. The photograph was taken by J. Veenstra from a building window on the north side of the city of Arnhem. The photograph was made by time exposure with a period of 10 sec. Rutgers did not specifically identify the trace as that of a ball lightning, but rather compared it to an earlier photograph, that by H. Jack. shown in Figure 5.10, and indicated similarity.

The photograph in Figure 5.32 was discussed by at least three lightning investigators of the period. Westphal (1958), F. Wolf (1958), and Toepler (1959, 1960) all agreed that the traces were not caused by a ball lightning. F. Wolf (1958) compared the images to those earlier reproduced by F. Wolf (1956a,b), Raab (1940), and Holtzer and Workman (1939). He noted the differences between the various images and suggested that the photograph in Figure 5.32 was caused by a

normal line discharge. He apparently accepted the validity of the other photographs, which are now suspect. Toepler (1959, 1960), however, recognized the erroneous nature of all these photographs and suggested that the images in question were some other form of electrical discharge phenomenon. Westphal (1958) was more direct and just stated that the image was not that of a ball lightning as a 10-sec duration was not consistent with the accepted characteristics.

Upon close examination of the photograph, it would appear that the other traces complicate the examination. Unfortunately, most are shaded by foliage and critical examination is not possible. Since the sources of the main and secondary traces are apparently beyond the foliage in the foreground, camera motion would not be a probable cause. It is possible that a line discharge did occur as suggested and

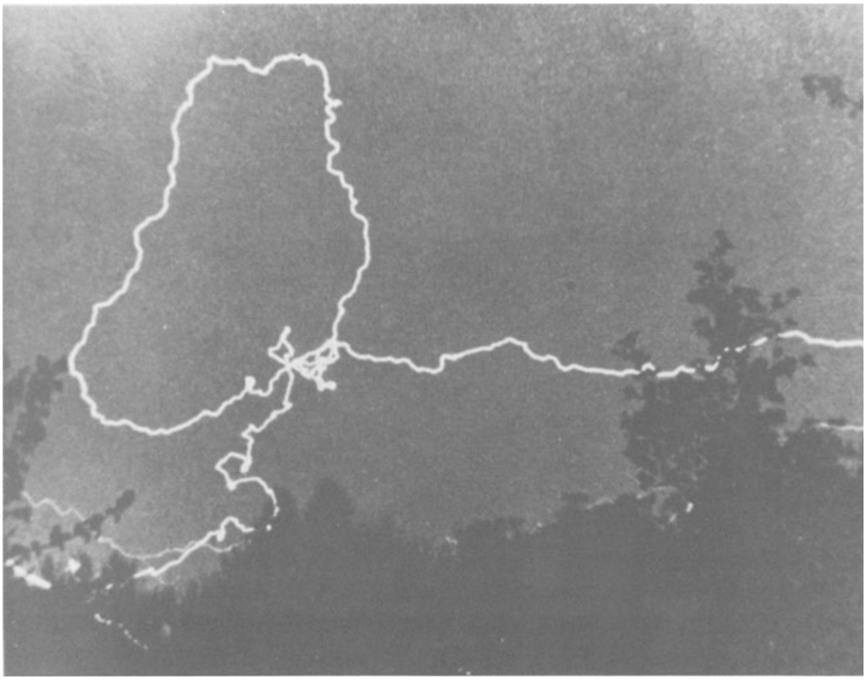

Figure 5.32. Still camera photograph of an illuminated object taken by J. Veenstra from a window in the city of Arnhem in 1958. It was initially thought similar to the trace of H. Jack shown in Figure 5.10. The photograph was discussed by Westphal (1958) and Wolf (1958), who agreed that it had not been caused by a ball lightning. Other characteristics also indicate that it may not have been caused by a ball lightning. Reprinted with permission of Verlag Chemie International, Publisher of *Physikalische Blätter* from G. A. W., Rutgers, "Ein Kugelblitz?," *Physik. Blätter,* **14,** 1958, p. 417.

create the images as recorded. Because of the lack of any supportive witness data, there is no substantial support for the interpretation of the traces as being of a ball lightning.

A fairly obvious photograph erroneously connected to ball lightning was published by Trier (1960) following the discussions of such photographs by Toepler (1960). Trier illustrated that a continuous luminous line image without supportive data cannot be seriously identified as a ball lightning trace. Israel (1960), in a companion discussion, indicated his earlier criticisms (Israel, 1958) and that of Bauer (1938), which referred to several photographs reported to have been of ball lightning. He referred to those published by Kuhn (1951), F. Wolf (1956a,b), and Zoege von Manteuffel (1938), which were shown in Figures 5.20, 5.10, and 5.7, respectively. Israel also reproduced another photograph that had a similar appearance but was intentionally created by camera motion.

The difficulty with the interpretation of uninterrupted line images as being representative of ball lightning is emphasized by the large number of photographs of natural lightning available with similar images. The next section addresses these images and illustrates the difficulty in interpretation.

5.2.7. *Class 7: Natural Discharges*

This class contains photographs of natural events erroneously mistaken for ball lightning, or other photographs that are not those of ball lightning but resemble those that have been identified as being of ball lightning.

Normal linear lightning is known to follow a complicated and occasionally tortuous path in its discharge through the atmosphere. The discharge action may be studied photographically, but only with a high-speed camera. In a camera used in lightning photography, the film may be moved rapidly horizontally or vertically. Film speeds of 500–1000 cm per second or greater are common. Such film speeds are needed as the lightning stroke can have a velocity of about 5×10^8 cm sec^{-1}

The photograph of natural lightning shown in Figure 5.33 was published originally by Holtzer, Workman, and Snoddy (1938) and reproduced by Holtzer and Workman (1939). The discharge strokes were of the dart leader type and occurred about 100 ft from the camera. The event was photographed by two moving film cameras providing stereoptic evaluation and also by still cameras.

Analysis of the photographs indicates that the discharge was not singular, but made up of at least four elements. The discharge velocity was about 10^7 cm sec^{-1}. The ball-like image is the result of the luminosity persistence due to closely spaced motion of the moving luminous dart strokes. The persistence lasted only about 10 μsec (1 μsec = 1×10^{-6} sec). It was recognized by Holtzer, Workman, and Snoddy (1938) that the ball-like luminosity was not due to a ball lightning. The spot was thought to be ordinary halation due to the complicated wandering of the stroke about a small volume.

It was thought that discharges of this type are not normal lightning in the usual sense of the term. The trace apparently resulted from secondary discharges which occur during violent thunderstorms and do not represent the main discharge type. The irregularity of the path and the reversal of direction of the stroke suggest extremely complicated and irregular electric fields near the ground. Such fields may be produced by space charge from corona points near the ground surface and modified by surface conductivity. These secondary discharges apparently occurred nearly simultaneously with the more extensive lightning strokes and may have been induced by the rapid change in electric field intensity which accompanies close lightning discharges.

The characteristics of the discharge in Figure 5.33 may be similar to those in Figure 5.28. Both discharges are extremely irregular and close to the ground. Based upon the evaluations of Figure 5.33, it would appear that Figure 5.28 may be explained in a similar manner. Although not originally identified as such, Figure 5.28 was later identified by several investigators as being of a ball lightning. It was, therefore, placed in Class 6. However, it is not considered by this author to be a valid ball lightning photograph.

The photograph shown in Figure 5.34 was taken near the location of Figure 5.33 and was originally published by Holtzer and Workman (1939). The photograph was made with a simple, hand-held, single-frame camera. Camera motion was not appreciable, as may be deduced from the obvious lack of blurring. The indistinct portion of the image was thought to be discharges from sharp points of a tree. The trace can be recognized as not being a ball lightning discharge. Rather, it is a rapidly variable stroke apparently responding to irregular and changing electric fields. It is quite similar to that shown in Figure 5.31, which may well have been caused by the same type of secondary dart strokes.

The photograph included in Figure 5.35 was published by Holtzer and Workman (1939) and shows a single narrow trace. The discharge occurred less than 50 ft from the camera. The camera was hand-held

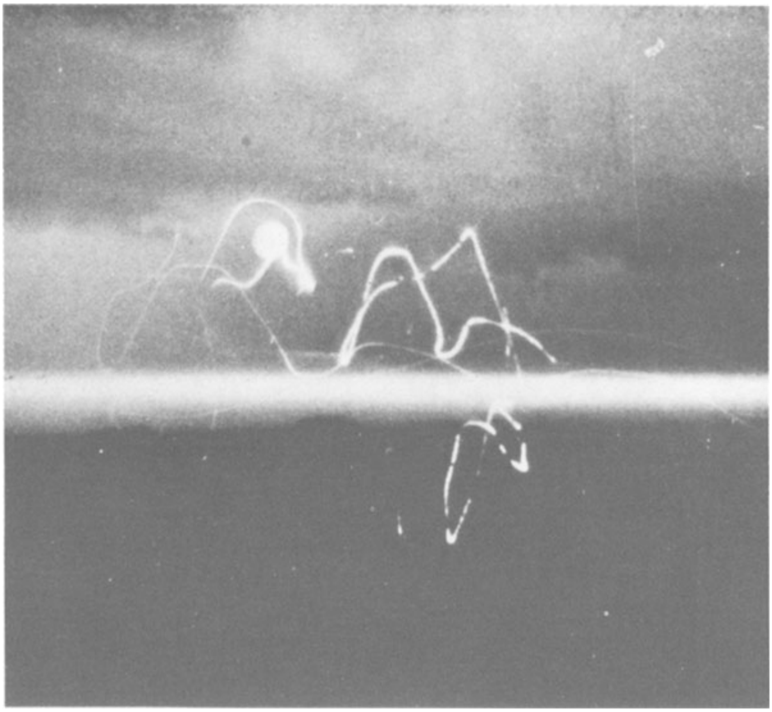

Figure 5.33. Fast moving film photograph taken during a lightning storm showing the rapid and random path taken by the dart leader portion of a natural lightning discharge. The motions in a small region would resemble a single image to the eye and to a still camera. Reproduced with permission from the *Journal of Applied Physics* and Dr. R. E. Holtzer. Originally published by R. E. Holtzer, E. J. Workman, and L. B. Snoddy, "Photographic Study of Lightning," *J. Appl. Phys.*, **9,** 1938, p. 134, and reproduced by R. E. Holtzer and E. J. Workman, "Photographs of Unusual Discharges Occurring during Thunderstorms," *J. Appl. Phys.*, **10,** 1939, p. 659, and by S. Singer, *The Nature of Ball Lightning*, Plenum Press, New York, 1971.

and no motion is apparent. This discharge is significantly different from those in Figures 5.33 and 5.34 in that it has a smoothly varying trace, not irregular. This photograph is similar to those shown in Figures 5.29 and 5.30. This photograph was not identified as having been made by a ball lightning but rather by a quasinormal lightning discharge. It would appear, by comparison, that the other two figures may have resulted from a similar natural discharge.

A photograph of a lightning discharge identified as a ribbon or curl type was reproduced by Stolterfoth (1899). It was not identified as a ball lightning but is quite similar to several of the uninterrupted trace type of photographs, as well as suggestive of camera motion. The

Figure 5.34. Still camera photograph taken during a storm showing the irregular path taken by secondary dart leader strokes of a natural lightning discharge. The photograph is not identified as a ball lightning but illustrates how such a rapid moving stroke in a small region could be so interpreted. Reproduced with permission of the *Journal of Applied Physics* and Dr. R. E. Holtzer. Originally published by R. E. Holtzer and E. J. Workman, "Photographs of Unusual Discharges Occurring during Thunderstorms," *J. Appl. Phys.*, **10,** 1939, p. 659.

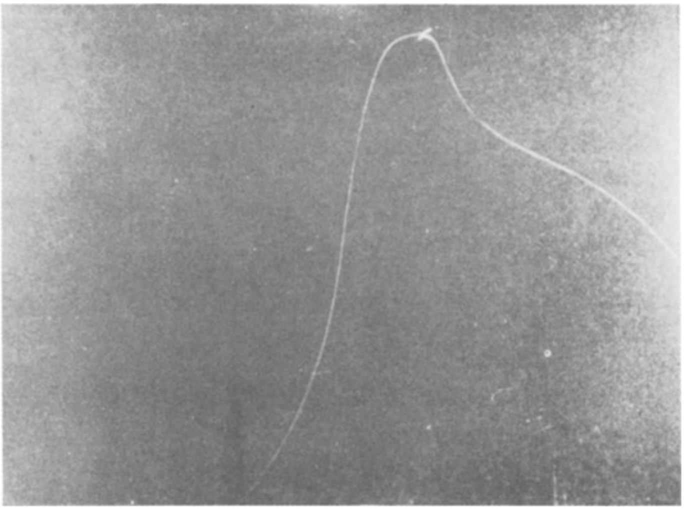

Figure 5.35. Still camera photograph taken during a storm and identified as having been caused by a natural lightning discharge. This figure is similar to others which were identified as ball lightning images. This figure further indicates the doubt and concern about the validity of identifying such traces as having been caused by a ball lightning. Reproduced with permission from the *Journal of Applied Physics* and Dr. R. H. Holtzer. Originally published by R. E. Holtzer and E. J. Workman, "Photographs of Unusual Discharges Occurring during Thunderstorms," *J. Appl. Phys.*, **10,** 1939, p. 659.

photograph of Stolterfoth (1899), as well as that of Steadworthy (1917), just further emphasizes the difficulty of source identification based upon a single photographic image.

The importance of the two photographs, Figures 5.33 and 5.34, in formulating a possible concept of the observed ball lightning phenomenon is clear. One form of ball lightning may well be the result of highly dense, momentary, space charges produced by intense and irregular electric fields and corona discharges near the ground surface. The apparently solid body of the ball lightning may result from the image halo caused by the rapidly moving dart stroke within a small volume of air. The persistent luminosity results from the continuation of the strength of a dense space charge and from the presence of the secondary dart stroke for many periods of normal luminosity, perhaps even thousands of times longer. Normal luminosity lasts for only about 10 μsec. Such a process could also provide an energy source for molecular excitation. The molecular excitation could produce visible radiation which if observed by witnesses could be interpreted as a ball lightning event. Refer to Chapter 7, Section 7.5.

5.2.8. Class 8: Artificial Phenomena

This class is characterized by photographs of laboratory-produced phenomena which have the appearance of a ball-lightning-like object or its apparent trace.

During the past century, as scientists became intrigued with the electrical phenomena, laboratory investigations were performed with charge-producing machines to produce lightning-like phenomena. Numerous experiments were performed and many analogies made between the results and various natural electrical phenomena, including ball lightning. The various ball lightning experiments are discussed in some detail in Chapter 7 and a number of photographs reproduced.

Perhaps the earliest photograph of a laboratory discharge reported to be that of an artificial ball lightning was that by Trowbridge (1907) and is reproduced here as Figure 5.36. He gives credit to the notable experimental work performed by Professor A. Righi, an Italian physicist, and Dr. Toepler, a German physicist. It would appear that Trowbridge produced the photographed discharges with an apparatus that was built according to Righi's design. A glow discharge was produced in a partially evacuated, enclosed, cylindrical glass tube. The electrodes at each end were connected to an elementary battery and high-voltage generator. Trowbridge postulated that the rarefied gas discharge is

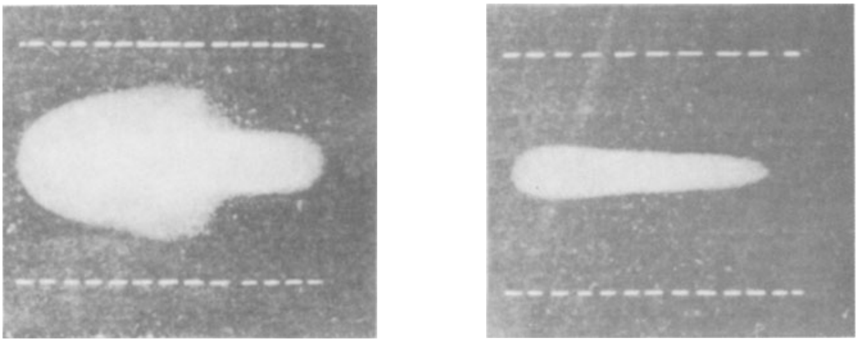

Figure 5.36. Still camera photograph of illuminated objects caused by controlled electrical discharge in a partially evacuated vessel during a laboratory experiment. The photographs were apparently from A. Righi or M. Toepler. Reproduced with permission from *Scientific American*, New York, after J. Trowbridge, "Ball Lightning," *Scientific American*, **96**, 1907, p. 489.

similar to that which occurs naturally in the rarefied gas channel of a lightning stroke. By analogy, ball lightning is a discharge evolved from normal lightning. This same concept has been considered in more detail by various workers in evolving a theory of ball lightning formation. Notable among these are C. E. R. Bruce (1963a,b), E. L. Hill (1960), Lewis (1963), Meissner (1930), Neugebauer (1937), and Ritchie (1963).

Although numerous investigators made analogies between glow discharges obtained in partially evacuated vessels with ball lightning, they were criticized on the grounds that the results were not probable at atmospheric pressure in nature. The investigation of spark propagation in air at atmospheric pressure and the nature of the corona discharge was investigated by numerous scientists. It was originally thought that the Townsend (J. S. Townsend, 1900, 1901) concept of spark formation was absolutely correct. That is, an initial electron liberated from a negatively charged cathode material causes electron multiplication by collisions as it progresses across the potential gap. The so-formed electrons and positive ions produce a space charge of sufficient density to support a spark.

Later theoretical and experimental work showed that the pure Townsend mechanism was not possible at pressures much above 100 mm Hg and gaps more than 3 mm wide. The major reason for modification of the Townsend mechanism was the discrepancy between the measured speed of the initial electron across the gap and that predicted by theory. The breakdown time suggested by theory was

greater than that observed. It is now known that the spark propagates by creation of secondary electrons produced by the initial electron(s) in the medium through which the discharge propagates.

That is, as initial electrons appear in a potential gap, space charge accumulates, and a rearrangement of the charges leads to the passage of current in the medium, which in turn causes more charge to be produced by action on the medium. The avalanche effect leads to the propagation of a spark. The spark is a discontinuous process which in itself is unstable, but it provides the transition between two stable conditions, no current flow and current flow—the discharge.

In atmospheric lightning discharges, the spark concept is replaced by that of the dart leader stroke. It is a highly mobile, intraair charge propagation which follows the space charge path of greatest density and effectively lowers the current resistance of the created path. It is then followed by the lightning discharge. It is also clear that the propagation of a discharge through the air produces, as well as follows, the regions of greatest charge density. The atmospheric discharge also follows inhomogeneities of the electric field in the air and in turn varies that field and creates another, but modified, inhomogeneous field. It is also clear now that the resulting ionization of the air will possess inhomogeneous properties due to the electric fields and space charges and will depend upon the different mobilities of the positive and negative charges.

The investigation of coronas and discharges in the air was outstandingly described experimentally and theoretically by Loeb and Kip (1939) and later by Sknowronek (1960). The secondary electrons generated by a positively charged particle striking a negatively charged point cathode were shown to lead to avalanche ionization of the surrounding gas. Visible light, of course, may be caused by the ionization of air molecules which radiate light as recombination occurs. In order for the discharge to propagate outward from the charged spot, ionization must proceed at increasingly larger distances. The initial discharge may be maintained for only a finite time as space charge mobility and negative and positive ion formation and migration will alter the initial discharge avalanche conditions. Should the applied field remain large or increase, avalanche ionization and discharge propagation will occur and advance outward in a periodic fashion. The terms "dart strokes" and "streamers" are used to refer to this propagation process.

Whenever the process is self-sustaining, that is, when it has grown to a distance of many electron mean free paths from the charged spot, a corona is created. The corona is visible to the eye because of the energy of the radiation generated. Leob and Kip (1939) made numerous

photographs of corona generation and several are reproduced here. The left portion of Figure 5.37 shows a corona glow surrounding a positive point. The right portion shows the streamers which may be superimposed on a corona glow as the discharge propagates outward. Figure 5.38 shows the presence of breakdown streamers across the potential gap from a positively charged point. Visually, it appears that new streamers overtake old streamers and provide propagation through the gap.

The laboratory-produced corona discharges and the atmospheric corona discharge called St. Elmo's Fire are directly analogous. Such corona discharges may be produced from either negative or positive point electrodes. In nature, as the ground is normally positively charged during a thunderstorm, the upper tip of an object that is raised above the earth plane becomes the positively charged point. The resulting corona discharge has been observed repeatedly over many centuries.

However, it is a well-established feature of corona discharges that independent mobility is not allowed by the conditions of the discharge process. The corona may not detach itself from the charged point and wander about in the air as the corona is maintained by the presence of intense electric fields formed about the point. It is the property of

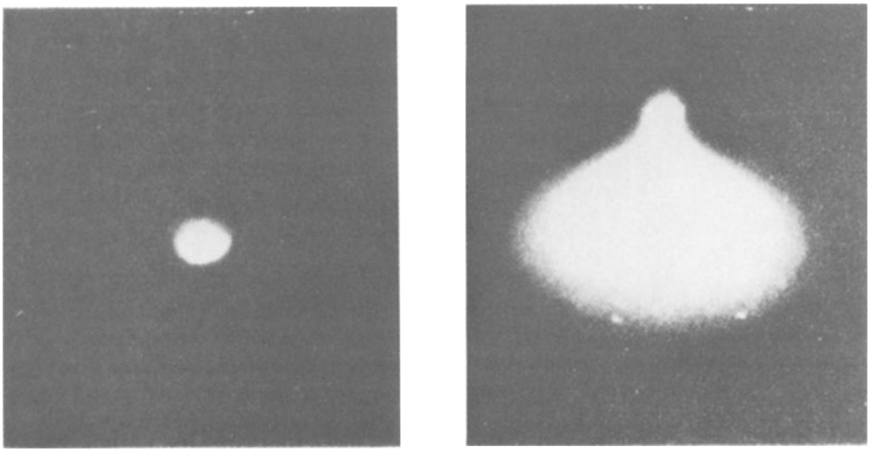

Figure 5.37. Still camera photograph of an illuminated discharge corona phenomenon created in a laboratory cell. The corona flow and burst streamers were observed to appear from a 2-mm-diameter positive point electrode above a plane electrode. Reproduced with permission of Professor L. Loeb and the *Journal of Applied Physics*, and reprinted from L. G. Loeb and A. F. Kip, "Electrical Discharges in Air at Atmospheric Pressure, The Nature of the Positive and Negative Point-to-Plane Coronas and the Mechanism of Spark Propagation," *J. Appl. Phys.*, **10,** 1939, p. 142.

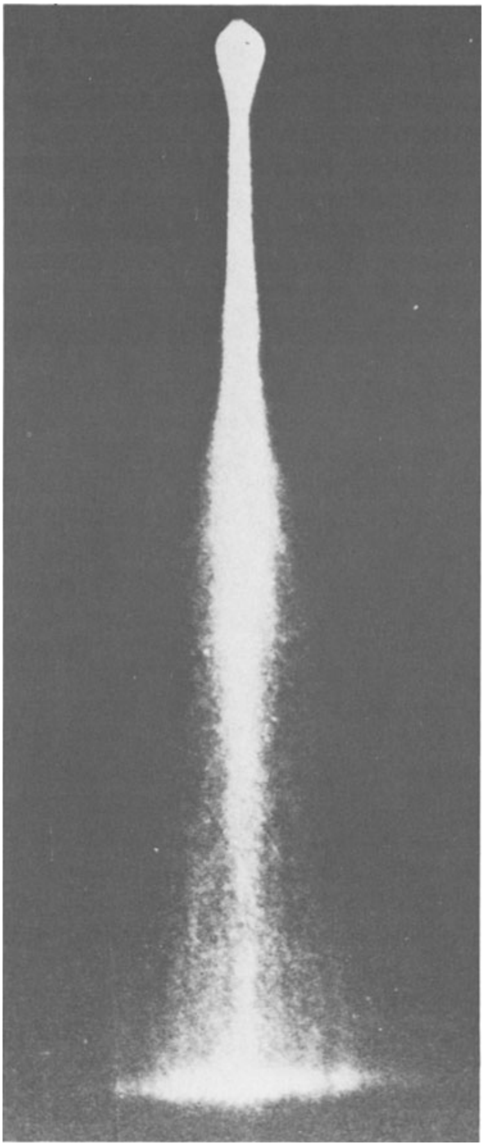

Figure 5.38. Still camera photograph of an illuminated breakdown streamer created in a laboratory cell. The discharge was caused to occur between a positive point electrode and a plane electrode. The similarity to previous figures is obvious. Reproduced with permission of Professor L. B. Loeb and the *Journal of Applied Physics* and reprinted from L. B. Loeb and A. F. Kip, "Electrical Discharges in Air at Atmospheric Pressure," *J. Appl. Phys.*, **10,** 1939, p. 142.

mobility that separates the ball lightning phenomenon from St. Elmo's Fire. The photographs that accompany witness reports of independent mobility of the ball glow may not be classed as corona discharges. But those that were observed to remain stationary may be so denoted. To that end, we should classify both Figure 5.25 and Figure 5.26 as questionable.

That laboratory-produced ionized air may resemble the reports and photographs of natural phenomena identified as ball lightning is indisputable. Basically, we have found that ionized air, that is, low-density air plasmas, do resemble the ball lightning. Plasmas may be produced by familiar electric potential means or with high-frequency electromagnetic fields. Much work has been done with the generation of plasmas and the investigation of the problems of plasma confinement.

The fundamental work on the properties of a high-frequency plasmoid was by Wood (1930b). The term "plasmoid" was applied to the general luminous forms which were formed by the radiofrequency discharge. These forms include balls, spindles, and any other well-defined plasma entities generated by the radiofrequency discharge. The plasma is created by focusing radiofrequency radiation in the range 1–100 MHz (1 MHz = 1×10^6 cycles per second) within a partially evacuated vessel. The properties of the plasmoids have been observed to vary somewhat with pressure. Such plasmoids can be maintained at atmospheric pressure in air as well as in evacuated vessels.

A typical plasmoid formed between plane parallel electrodes is shown in Figure 5.39 after Hatch (1958). The electrodes are visible on the right and left sides of the figure. The excitation frequency was 15 MHz and the electrode separation was 25 cm. The pressure in the vessel was 0.3×10^{-3} mm Hg. The plasmoid was white, spherical in shape, and had a diameter of about 12 cm. At other pressures, the plasmoid varied in shape. It could become elliptical like an egg, flat and slightly thicker near the center like two saucers face-to-face, and the plasmoid could disappear suddenly as the pressure changed.

A related experimental technique, that is, electrodeless discharges, can produce similar phenomena. The plasmoid is formed at the focus of a parabolic radar antenna and may be projected some distance from the antenna. The early work of Babat (1947) demonstrated that electrical flames could be formed as a result of microwave breakdown of the air. Such electrodeless discharges can be produced in air and in other gases at normal pressure as corroborated by C. W. Hamilton (1960) and Ritchie (1963) working with an *X*-band radar transmitter. The transmitter used by Ritchie operated at a frequency of 9 GHz (1 GHz = 1×10^9 cycles per second) and generated a peak power of about 21 kW and an

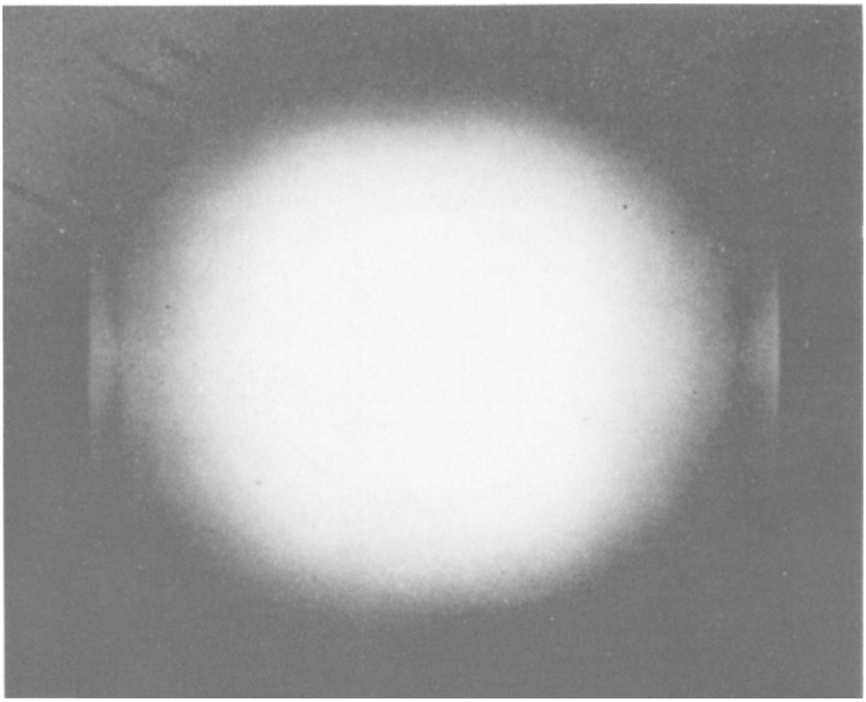

Figure 5.39. Still camera photograph of radiofrequency excited discharge in a partially evacuated cell during a laboratory experiment. Reproduced from A. J. Hatch, "Plasma Studies in a Low Pressure High Frequency Discharge," *Second International Conference on the Peaceful Uses of Atomic Energy,* Geneva, Proceedings, Controlled Fusion Devices, Vol. 32, 1958, p. 333.

average power of 50 W with 0.5 μsec pulse width and a pulse-repetition period of 290 μsec.

The plasmoid shown in Figure 5.40 after Ritchie (1963) was produced by this device in an evacuated glass chamber of about 5 in. in diameter. The pressure was varied from 0.1 to about 80 mm Hg and the glass vessel was located about 60 cm away from the antenna. The shape and color of the electrodeless discharge varied with pressure, as with the discharges produced by Loeb and Kip (1939). Colors ranged from transparent, red, violet, to blue, and shapes from spherical to sausage and others with halos were observed. It is required that an initial ionization must occur in the discharge vessel before air breakdown will occur. Only after a certain level of preionization has been established will the electrodeless discharge ignite.

The light emission from the plasmoid was not found to have been continuous but rather periodic following the microwave pulse. The microwave pulse was essentially quasi-square-shaped in time with a period of 0.5 sec. The light emission had a build-up period of 0.4 μsec and decayed slowly, reflecting the dissipation of the ionized species in the plasmoid. The intensity of the light emission fell to zero in about 1 μsec.

A similar radiofrequency discharge was produced by Geerk and Kleinwachter (1960). The discharge was produced at a pressure of 10–40 Torr (1 Torr = 1 mm Hg) within a vessel positioned at the focus of the microwave antenna. The microwave frequency was 10 GHz and a power of 40 kW was used. A photograph of the discharge was also published. It had an appearance quite similar to that of Ritchie (1963).

A relatively long-lived electrodeless discharge can be produced in air with a 75 MHz radiofrequency generator. Powell and Finkelstein

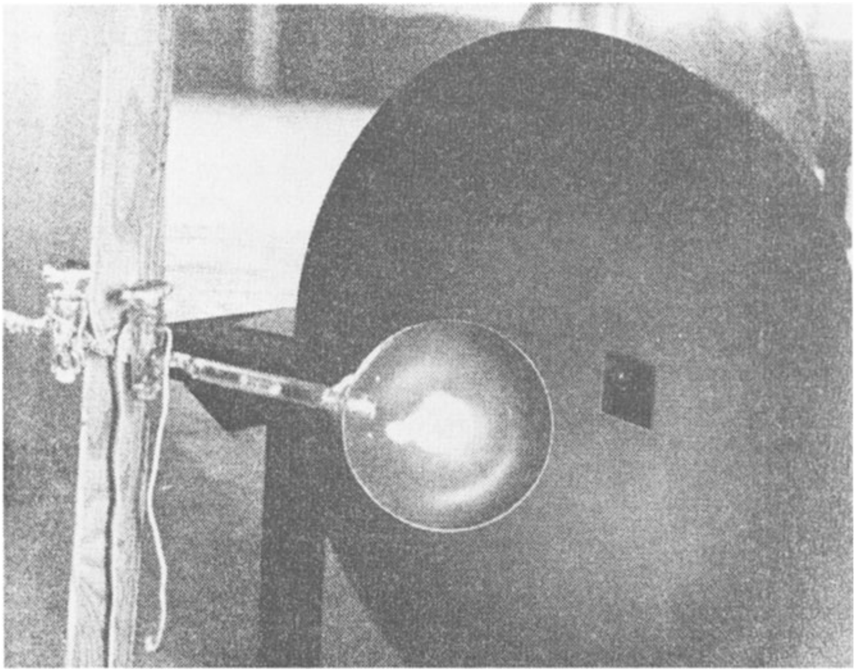

Figure 5.40. Still camera photograph of a radiofrequency discharge caused to occur within a partially evacuated cell. The radiofrequency energy was focused into the cell by a parabolic radar antenna. Reprinted from D. J. Ritchie, "Ball Lightning in Nature and in the Laboratory," *Inst. Electr. Engr. J.*, **9**, 1963, p. 202.

(1969, 1970) produced such atmospheric pressure discharges. One of their photographs showing the experimental result is reproduced in Figure 7.14. The luminosity is attributed to emission from CO_2 molecules which were excited to metastable electronic states by the discharge. The luminosity lasted about 1 sec after the radiofrequency energy was terminated and about 1/2 sec in open air. It was though that the shorter life in open air was due to faster convection mixing in the unconfined space.

The life of the emission was strongly affected by the composition of the electrodes. If high-vapor-pressure electrodes were used, the luminosities persisted. If low-vapor-pressure electrodes were used, the luminosity disappeared more rapidly when the radiofrequency arc was terminated.

The color of the discharge was related to the ratio of N_2 and O_2 in the atmosphere. A N_2 luminosity was blue while that in O_2 was white. Ordinary air with 20% O_2 was yellow-white. The yellow was due to the increasing presence of NO_2 in the discharge. N_2O luminosities were orange and larger than those in air and lasted about 2 sec after termination of the radiofrequency discharge.

The use of the various experimental means to produce a ball-lightning-like object should not be judged as validating a type of formation mechanism or an existence process. There need not be an analogous mechanism or process in nature. The various experimental methods were used to concentrate energy into a small well-defined region of laboratory air. Controlled atmospheric discharges were not readily available. Additionally, most experimental results were caused in evacuated cells and used excitation means not probable in nature. Refer to Chapter 7 for more details on experimental investigations.

5.3. Unavailable Photographs

A number of photographs mentioned in one reference or another were unavailable to this author. Baltin (1902) and Zschokke (1903) apparently both published photographs which were originally identified as being that of a ball lightning. Walter (1903, 1929), however, investigated the incident, and after examining the photographs attributed them to a street lamp with the apparent motion caused by camera motion. Walter (1903) also discussed a photograph taken by M. Wolffe in Berlin in 1902 and illustrated that the multiple traces were also caused by camera motion. The Wolffe photograph has not been available to this author.

Prochnow (1928) published numerous lightning photographs in his book *Erdball und Weltall.* Three photographs were identified as those of ball lightning phenomena. Walter (1929) was quite skeptical, suggesting that the images were of street lamps and the traces were caused by camera motion. Prochnow (1930a,b) defended the accuracy of the photographs, reproduced a few of the questioned photographs, and discussed the events in much detail. Raab (1940) published a photograph and apparently discussed other evidence of a ball lightning observation. F. Wolf (1956a) referred to the photograph and suggested that it was similar to those published by Holtzer and Workman (1939). Raab apparently made personal observations as well.

Rossman (1949) published a ball lightning photograph which was later discussed briefly by Kapitza (1958). Schneiderman (1934) also reportedly published several photographs in a trade newspaper with wide distribution. One of the photographs was later reproduced by Norinder (1939, 1965). A ball lightning photograph published by Stekol'nikov (1943) was discussed by Kapitza (1958). The photograph by G. F. Townsend (1895b) was made before the turn of the century and may be similar to that by Riggenbach-Burckhardt (1897).

The photograph published by F. Wolf (1956a) was apparently identical to that published by F. Wolf (1956b) elsewhere. Dunn (1894) was reported to have published two photographs of objects identified as ball lightning. Mathouillot (1908) presented two photographs of ball lightning (*foudre globulaire*) to the French Academy of Sciences. The two photographs were not reprinted in the journal.

6

Skepticism

6.1. Inferences

Ball lightning skepticism is not a recent response of scientists and evaluators of the available data. It has been noted that M. Faraday and F. Arago, both eminent scientists of their period, questioned the existence of ball lightning. Faraday (1839) suggested, "that the phenomena of balls of fire may appear in the atmosphere, I do not mean to deny; but that they have anything to do with the discharge of ordinary electricity, or are at all related to lightning or atmospheric electricity, is much more doubtful."

Many investigators, professional meteorologists, and weather observers remain skeptical of the reality of ball lightning. Arago (1854), O. Lodge (1905), von Schiodt (1893), and Tomlinson (1888a–d), for example, were skeptical during the period when interest in any electrical phenomena stimulated much activity. More recently, Berger (1973) reported that in over 20 years of study as a meteorologist and lightning investigator he has never observed a ball lightning. Based on that fact and on documented evidence from a large number of ball lightning reports which were proved erroneous, he concluded that there is no such phenomenon as ball lightning. A number of investigators, for example Ashmore (1940) and Humphreys (1936), could find no substantial verification of a ball lightning that could not be interpreted in another more natural manner. Humphreys (1942) was more direct—he suggested that the ball lightning concept was humbug.

However, several eminent scientists have reported natural ball lightning observations, including, Loeb (1966), Marsh (1895, 1896a,b, 1899), and Rotch (1903a,c). Caballero (1890b), a professor of physics, reported an observation of a ball lightning occurrence in 1890 which was also observed by another professor. It was also indicated by

Shunaman (1976) and Tuck (1971) that Niels Bohr and Victor Weisskopf had reported observations of a ball lightning.

It could be argued, of course, that the lack of definitive data is simply a result of the rarity of the ball lightning occurrence. Even Schonland (1950) agreed that all reports cannot be erroneous and some phenomenon other than an extreme form of St. Elmo's Fire must exist. The major difficulty is the inability to study ball lightning at will. This is probably the most prevalent objection made by scientists attempting to evaluate the phenomenon and discuss its origin and physical substance.

The unbiased examination of ball lightning reports leads one to conclude that a great percentage of the reports are highly questionable and could be interpreted in several ways. For example, since many observations of ball lightning are reported to occur during normal lightning activity, it is quite reasonable to conclude that some reports may be optical illusions caused by a residual image retained by a dazzled eye. In addition, as St. Elmo's Fire does have some characteristics similar to those of ball lightning, it may be assumed that even more reports are the result of mistaken identification.

St. Elmo's Fire is a well-known luminous phenomenon occasionally observed during thunderstorm activity and during other electrical events in nature. It has been extensively studied in the laboratory, for example, by Toepler (1898b,c; 1899; 1959; 1960). St. Elmo's Fire is the visible result of a corona discharge from some object protruding above the ground. The intense voltage potential difference between ground and cloud created during adverse weather conditions can cause an intense electric field to develop about the object. The intense electric field is a result of the geometry and conductance of the object. The electric field of a pointed or short radiused object is far greater, for example, than a smoothly radiused or flat object.

The intense electric field can cause electron emission from the object, which can in turn lead to dissociation and ionization of the air molecules. The recombination of these molecules liberates radiative energy whose wavelengths may be within the visible spectrum. An observer would describe the luminous form as a glowing ball hovering above or moving about the source object.

St. Elmo's Fire, as discussed for example, by Brand (1923) and Neunteufl (1951), has an oval or ball shape about the size of a large orange, and a blue or blue-white glowing appearance. However, diameters much larger than 30 cm have been observed. It decays silently, although the decay may be sudden or slow. Its lifetime is longer than that of a ball lightning, usually many seconds, or even minutes.

A characteristic distinction between St. Elmo's Fire and ball lightning is the apparently independent motion of the latter. Although St. Elmo's Fire has been observed to move about, it may move along a conductor, sometimes pulsating as it moves, but it does not free itself from the conductor. Thus, it does not exhibit the descending, hovering, or flying motions that are common to ball lightning. Objects observed near electrical wires during storms have been reported as ball lightning. Bowman (1949), Carruthers and Foster (1947), Ekvall (1957), Funder (1939), and Palazzo (1903) reported examples of this type. But these phenomena are probably actually St. Elmo's Fire.

In addition, luminous phenomena observed during thunderstorms, for example, as reported by Zaleskii (1958), are certainly examples of St. Elmo's Fire and not ball lightning.

Another form of St. Elmo's Fire not obviously attached to a conductor has been postulated by Callahan and Mankin (1978) as being responsible for unidentified luminous clouds and objects occasionally observed moving through the lower atmosphere at night. They suggested that nocturnal swarms of insects may emit corona light when moving through high electric fields caused by natural events, such as thunderstorms and blowing dust. A number of common insects that travel in swarms were subjected to laboratory electric fields of order 2 kV cm^{-1} and were observed to emit visible light. The light intensity was measured at a distance of 18 cm from a glowing insect as about 4×10^{-6} W cm^{-2} and was quite visible to the human eye in a darkened room at about 6 m (19.7 ft). That such a phenomenon would be possible in nature was supported by electric field measurements in the vicinity of thunderstorms. Electric field values from 1 to 3 kV cm^{-1} were measured with aircraft in a study discussed by Callahan and Mankin (1978).

The dependence of St. Elmo's Fire on a nearby conductor would appear to be violated by the suggestions and experiments of Callahan and Mankin (1978). However, the corona discharge occurring on the body of insects arises as a result of their body structure. The insect body shell with the various member projections forms a dielectric conductor with sharp points that emphasize the electric field intensity. The body fluids of the insect form an electrolyte. When the insect is immersed in an electric field, corona discharges occur from the points on the dielectric conductor. A living insect produces the discharge phenomenon while a dead one will not.

A relationship between ball lightning and the St. Elmo's Fire discharge has been suggested many times. It has been postulated that some rarely occurring situation leads to the transformation of St. Elmo's Fire into a ball lightning. Such an observation has been reported only

twice among the more than 1100 reports accumulated by this author. Kerkhoff (1913) and M. Scott (1878a) reported that a glowing ball, initially hovering above an object on the ground, suddenly moved away, free of its attraction for the grounded object. Such observations, although rare, may represent the only observations of the origin of a ball lightning. The observations may also be of events of the type suggested by Callahan and Mankin (1978). Most ball lightning events are first observed after the luminous form has apparently been in existence for some period of time. Reports emphasizing the observational origin of ball lightning are noticeably nonexistent among the infrequent ball lightning reports themselves. Consequently, the very existence of ball lightning as a single, separate, individual, distinctive occurrence has been questioned.

6.2. *Optical Illusions*

Ball lightning is considered by many to be nonexistent, the vast number of reports being merely optical illusions and afterimages. Proponents of this point of view include M. Argyle (1838), E. Argyle (1971), Evershed (1889), Hagenguth (1951), Humphreys (1936), Malan (1963), Sauter (1895), von Schiodt (1893), Schonland (1962a,b), Szpor (1977), Trowbridge (1907), and Verdet (1890). It is normally argued that the afterimage created in the eye of the observer is due to the luminous intensity of an ordinary lightning stroke.

In a recent study of ball lightning observations, Rayle (1966) found that many witnesses initially observed the ball lightning at the impact point of a normal lightning stroke to the ground. The number of such observations was almost half of those reporting ball lightning observations in the same study. It was considered likely by Fieux, Gary, and Hubert (1975) that a cloud-to-ground stroke could cause momentary intense illumination at the ground due to vaporized particulate matter at the termination point.

The complexity of visual afterimages is well known and has been investigated in numerous psychological and psychovisual studies. The occurrence of the negative afterimage is more common than that of the positive afterimage. The positive afterimage results from the visual observation of a bright illumination source that is intense relative to the background. The positive afterimage is an effect of the cone portion of the eye and is normally formed near, but not at the center of, the retina.

The observer, of course, will attempt to center the apparent object. The image, therefore, appears to drift across the observer's visual background as the eye muscles attempt to correct the centering error. Consequently, there is apparent motion of the object.

A characteristic of the positive afterimage is the retention of the image for some time and the motion of the image in unusual ways. For example, the afterimage may be perceived to pass through closed windows and other materials. Of course, no damage is reported, and the image does not change during the penetration. Such behavior is occasionally reported for ball lightning.

Positive afterimages last for 2–10 sec depending upon a variety of circumstances. Positive afterimages, of course, disappear suddenly and without noise. No sound is produced by positive afterimages, but sound may be reported by the observer because of other events in the environment. These characteristics are certainly similar to those reported for ball lightning.

E. Argyle (1971) reported that ball-lightning-like drifting positive afterimages could be induced by using flash bulbs and strobe lights as intense sources of illumination. Dr. C. Kennedy experimented with the perception of positive afterimages in his photographic dark room during the preparation of photographs for this author in 1977–1978. The image was perceived about 1–2 sec after the intense flash created by a xenon lamp. The image would last up to 15 sec after the flash. The image could be caused to disappear suddenly and silently by eye movement. The positive afterimage could be repeatedly produced in a dark room but was not detectable in a dimly lit room. Apparently, the appearance of the afterimage to the eye is dependent upon the contrast of the flash and the lack of discernible images in a dark room just prior to the flash.

Strong disagreement with the point of view that ball lightning is simply erroneous identification has been expressed by W. N. Charman (1971b), Davies (1971), and Jennison (1971). A major objection is that ball lightning phenomena have been observed by several witnesses simultaneously with like reports. An afterimage or optical illusion effects would be reported differently for different viewers as each would have his or her own perspective and orientation. In addition, as afterimages appear to be localized at or in front of the background against which the stimulating object was viewed, they would appear to recede or approach as the background recedes or approaches. Consequently, one would expect a common relationship between apparent diameter and distance. No such relationship is conspicuous in ball lightning reports.

It is to be noted that, historically, scientists also doubted the existence of meteorites, which were often reported by untrained observers.

6.3. Perceptual Effects

The reported characteristics of ball lightning have also been questioned by Charman (1971a) on the grounds that confusion frequently arises from perceptual effects. The reported characteristics of a ball lightning image may be doubtful since the observer must estimate the properties relative to known dimensions of objects found in the surrounding area. The dimensions of these known objects are then related to the apparent size, position, and appearance of the image, and the description is given with respect to the known details of the scene. Whenever an unknown object is observed against an unspecific background, such as the sky and poorly illuminated backgrounds at night, the observer must use his or her judgment of the scene to describe the unknown object.

Unfortunately, if dimensions and distances are highly doubtful, related estimates of the characteristics of the unknown object will be poor. Since details of distance and size are normally made relative to objects of known dimensions and distances, if the known background objects are further away than the unknown object, then the estimates of its true size will be larger than they should be. Conversely, if the known objects are near, then the size of an unknown object further away will be underestimated. In an environment with an abundance of known objects for comparison, such as within a room, descriptions will be more accurate.

In addition, there are other perceptual effects, which can affect the perceived motion of an object. For example, the appearance of motion can be caused by changes in the luminosity of the unknown object: Increasing luminosity is interpreted as motion towards the observer and decreasing luminosity as movement away. Dimensional changes in the object can also be interpreted as motion of the object by the observer: An increase in size is interpreted as motion towards the observer and a size decrease as movement away. Autokinetic effects caused by eye muscle motion can also create erratic movement or an inadequately perceived motion.

Thus, one must conclude that reported observations by untrained observers must be regarded as somewhat questionable. This may not mean that the phenomenon does not exist, but rather that its properties as derived from observer reports must be evaluated with caution.

6.4. Summary and Erroneous Identifications

It is clear from the presentation in Chapters 2 and 5 that most of the published bead lightning and ball lightning photographs are highly questionable. The basis for questioning the validity of the photographs was included in those chapters along with the reported photographs to allow them to be placed in the proper perspective.

The available photographs and reproductions of bead lightning and ball lightning are listed in Tables 6.1 and 6.2, respectively. Multiple photographs by a single author are represented by a single entry. Photographs or reproductions of artificially produced phenomena identified as ball lightning are shown in Table 6.3. A classic example of the problems associated with many of the photographs of the period near the turn of the century are those by Webb (1900) and Stokes (1900). Dotted images from street lamps formed by camera motion were interpreted as lightning-induced secondary discharges.

It is necessary to recognize that a photographic image alone does not provide a definitive basis for an assertion of the existence of a ball lightning phenomenon. Many photographs have been made that are similar to those published and identified as being of ball lightning. Jefferson (1963) published a photograph of a subsun taken from an aircraft. The image was described as an oblong, uncolored object. The image was caused by the reflection of the sun from ice crystals in a cirrus cloud.

A subsun image is visible only when a cloud is viewed from above

Table 6.1. Photographs or Reproductions Identified as Being of Bead Lightning

Figure[a]	Source
2.1 (15), 2.2 (15)	Riggenbach-Burckhardt (1897)
2.4 (16)	Seigner (1966)
2.5 (17)	Schmauss (1909)
2.6 (17)	Prochnow (1930a)
2.7 (18)	Scheminzky and Wolf (1948)
2.9 (20)	Matthias and Buchsbaum (1962)
2.10 (21)	Young (1962)
2.11 (22)	Hubert (1975a)
2.12 (23)	McCrosky (1971)
2.13 (24)	Tompkins and Rodney (1977)
2.16 (29)	Touchet (1931)

[a] The numbers in parentheses are the page numbers on which the figure appears in this book.

Table 6.2. Photographs or Reproductions Identified as Being of Natural Ball Lightning

Figure[a]	Source
5.1 (82)	Dmitriev (1971a,b)
5.3 (84)	Jennings (1962)
5.4 (86)	Abbot (1934)
5.5 (87)	Muller-Hillebrand (1963)
5.6 (88)	Shagin (1960)
5.7 (89)	Zoege von Manteuffel (1938)
5.8 (90)	Young (1934)
5.10 (92)	Wolf (1956a,b)
5.12 (94)	Bauman (1937)
5.13 (95)	Merhaut (1944)
5.16 (98)	Tompkins and Rodney (1977)
5.17 (100)	Eriksson (1977a)
5.18 (102), 5.19 (103)	Jensen (1933)
5.20 (104)	Kuhn (1951)
5.21 (105)	von Haidinger (1868a)
5.24 (108)	Norinder (1939)
5.25 (109)	Charman (1976)
5.26 (110)	Geist (1949)
5.27 (111)	Prochnow (1930a)
5.28 (112)	Cartwright (1938)
5.29 (113)	Petersen (1954a,b)
5.30 (115)	Davidov (1958)
5.31 (116)	Dmitriev (1971a)
5.32 (117)	Rutgers (1958)

[a] The numbers in parentheses are the page numbers on which the figure appears in this book.

Table 6.3. Photographs or Reproductions Identified as Being of Artificially Produced Ball Lightning

Figure[a]	Source
5.22 (106), 5.23 (107)	Brand (1923)
5.36 (123)	Trowbridge (1907)
5.40 (129)	Ritchie (1963)
7.2 (154), 7.3 (156)	Hubert (1975a)
7.5 (161)	Plante (1884b)
7.6 (162)	Plante (1877c)
7.11 (172)	Barry (1966)
7.14 (188)	Powell and Finkelstein (1969, 1970)

[a] The numbers in parentheses are the page numbers on which the figure appears in this book.

when the ice crystals form a sort of mirror. The angle of the subsun from vertical is equal to the elevation of the sun. That a photograph of a subsun image could be considered to be that of a ball lightning is obvious if the photograph was viewed without knowledge of the true facts. However, a subsun cannot normally be viewed under conditions related to the observation of ball lightning.

Many of the older photographs must be suspect mainly for their age. Photography, as a wide-spread and generally available craft, had not advanced too far by, say 1930, and photographs made during the early years often reflect the uncertainty in photographic equipment and materials. The older photographs, especially those prior to 1900, often illustrate the confusion that can arise from an interpretation of an image without full knowledge of the events surrounding the occurrence.

Several bead lightning photographs were discussed in Chapter 2 with respect to the images caused by illuminated sources—street lamps—and camera motion. Figure 2.3 is a photograph made by Behn (1903) to demonstrate the result of intentional camera motion. Walter (1929) also made a similar suggestion. The photographs by Riggenbach-Burckhardt (1897), Figures 2.1 and 2.2; Seigner (1966), Figure 2.4; Schmauss (1909), Figure 2.5; Prochnow (1930a), Figure 2.6; and Scheminzky and Wolf (1948), Figure 2.7, were all apparently erroneously identified as those of bead lightning.

It is thus obvious that most photographs reported to be of natural bead lightning are misidentified. Malan (1961) commented that one photograph reported to have been of bead lightning was critically evaluated by Dr. Berger, the lightning scientist. Upon evaluation of the original negative, he found that the emulsion had been eaten away in a criss-crossed manner by insects. The result was an image interpreted as a bead lightning. This example just further emphasizes that photographic evidence, and especially still camera photographs, must be carefully evaluated and remain suspect until proven otherwise. Singer (1971) also discussed this problem.

The photographs by G. A. Young (1962), Figure 2.10, and Hubert (1975a), Figure 2.11, were those of mechanically induced lightning discharges with persistent luminosity of the discharge channel. The channel geometry characteristics of the luminous phenomena do not agree with all those normally attributed to bead lightning. However, the photographs may be considered valid examples of one form of bead lightning.

The photographs of Matthias and Buchsbaum (1962), Figure 2.9; McCrosky (1971), Figure 2.12; and Tompkins and Rodney (1977), Figure 2.13, are similar to the induced discharges in that they do not

reflect the channel geometry characteristics normally attributed to natural bead lightning. These photographs may be the only examples of natural bead lightning available.

Based on the five or six accepted photographs of bead lightning, namely, Figure 2.10, G. A. Young (1961); Figure 2.11, Hubert (1975a,b); Figure 2.9, Matthias and Buchsbaum (1962); Figure 2.12, McCrosky (1971); Figure 2.13, Tompkins and Rodney (1977); and possibly Figure 2.16, Touchet (1931), we must revise the definition of bead lightning.

"Bead lightning" must be the term applied to the apparent persistent illumination that may occasionally remain after a normal cloud-to-ground lightning stroke. The channel illumination is nonuniform, segmented, and composed of singular elements of somewhat different sizes and shapes. The distance between illuminated elements may be variable. The persistent illumination may remain for about 1 sec. The channel has no apparent specific longitudinal cycle.

The definition is somewhat different from that widely accepted and discussed in Chapter 2. The major differences are that bead lightning as found by this evaluation of the photographic evidence does not appear to be predominantly a cloud-to-cloud phenomenon, the channel does not have a cyclic sine-wave-type form, the illuminated elements are not necessarily spherical, and the separation between elements is not uniform.

In a similar evaluation, many of the photographs and reproductions listed in Table 6.2 and identified as being those of natural ball lightning are also erroneous. It was found that camera motion and typical illuminated sources such as street lamps could produce photographic effects similar to those associated with ball lightning. The photographs by Jennings (1962), Figure 5.3; Abbot (1934), Figure 5.4; Muller-Hillebrand (1963), Figure 5.5; Shagin (1960), Figure 5.6; Zoege von Manteuffel (1938), Figure 5.7; Young (1934), Figure 5.8; and Wolf (1956a), Figure 5.10, were all suspect because of the considerations of Behn (1903), Figure 2.3; Poulter (1935), Figure 5.9; and Bauer (1938), Figure 5.11.

In addition, the objects in the photographs by Cartwright (1938), Figure 5.28, and Davidov (1958), Figure 5.30, were not observed and may be explained in a similar manner. It is recognized, however, that these latter photographs may be of natural lightning rather than having been caused by a lamp and moving camera. The studies of Holtzer, Workman, and Snoddy (1938), Figure 5.33; Holtzer and Workman (1939), Figure 5.34; and Holtzer and Workman (1939), Figure 5.35, clearly illustrate the similarity among the photographs. Natural dis-

charges are frequently composed of rapidly moving dart strokes which can form a complicated path in space in response to localized time-dependent electric fields and space charges. The photography of such discharges with a still camera can, as we have seen, lead to erroneous identifications. In addition, a lightning channel can terminate above ground, and, if viewed in cross section, the end could be interpreted as a ball lightning. This concept was attributed to C. F. Varley by Anon (1885f) and discussed as a spurious ball lightning by Ashmore (1940).

The photograph by Petersen (1954a,b), Figure 5.29, is similar to that by Davidov (1958) except that the Petersen object was witnessed and reported to have moved slowly. Subsequent discussions, mainly by Poulter (1954a,b), have led to serious questioning of the validity of the photograph. The Davidov photograph was not verified.

The photograph published by Dmitriev (1971b), Figure 5.31, was reportedly observed by several witnesses. The photograph is extremely difficult to examine in detail and extract definitive information. The trace does have a similarity to Figure 5.35 by Holtzer and Workman (1939) and may have been caused by a natural discharge. The photograph cannot be accepted without reservation at this time. The photograph by Rutgers (1958) was questioned by Westphal (1958) and Wolf (1958), and it is not considered to be of a ball lightning.

The photographs by Bauman (1937), Figure 5.12, and Merhaut (1944), Figure 5.13, may represent the early formation of a ball lightning. The photograph by Norinder (1939), Figure 5.15, does not depict a ball lightning, but rather the reported origin. Since most still camera shutter speeds are 1/125 sec or slower, and the lightning discharge can occur in tens of milliseconds, it is not surprising that the completed ball lightning, if it may in fact evolve from a normal lightning channel, has not been captured on film. However, these photographs do not constitute good evidence as they stand—even supported by reported observational information, which may be suspect.

The pyrotechnic type of ball lightning, as represented by the photographs and drawings of Jensen (1933), Figures 5.18 and 5.19; Kuhn (1951), Figure 5.20; and von Haidinger (1868a), Figure 5.21, do have appearances similar to one another and to other reports. However, the Kuhn (1951) photograph is of a rising ball lightning, which is exceedingly rare indeed. The photographs of Jensen (1933) may resemble fireworks as suggested by Berger (1973) even though Salanave (1965) was convinced, after careful investigation, that the image was not produced by fireworks. Szpor (1977) was more critical and rejected Jensen's photographs as well as suggesting that all ball

lightning reports were erroneous. We must recognize, while not accepting Szpor's extreme position, that most photographs may be erroneous, since there is a lack of supportive information.

The photographs and drawings that show a single illuminated object, Norinder (1939), Figure 5.24; Charman (1976), Figure 5.25; Geist (1949), Figure 5.26; and Prochnow (1930a), Figure 5.27, are all suspect for reasons already discussed. Normal electric lights and natural phenomena, such as St. Elmo's Fire or normal lightning, could have produced such traces or observations. The photograph by Norinder (1939) was supported by observational data and Norinder's scientific inquiry. However, the problem remains that all of these figures could be explained in a more natural manner.

We are, therefore, left with only three photographs that are not obviously erroneous or highly suspect and might be reasonably considered as representative of natural ball lightning. The photograph by Dmitriev (1971a,b), Figure 5.1, is not a totally qualified example as it too could have been intentionally produced. The apparent lack of camera motion and the other illuminations, natural and artificial, in the photograph—coupled with the residual material found at the termination point—tend to support its interpretations as genuine. However, few details are available for evaluation.

The photograph by Tompkins, Rodney, and Gooding (1975), Figure 5.16, may be considered to be one example of a natural ball lightning photograph. It has several attributes that make its interpretation as that of a natural ball lightning more convincing. It was obtained by a remote automatically controlled camera. The camera shutter was mechanically chopped and operated at a relatively high rate, $33\frac{1}{3}$ Hz. The persistent illuminated passage of a moving phenomenon could therefore be separated from that of a normal lightning stroke. Since the camera was firmly fixed, no camera motion was possible. In addition, on at least two to four separate occasions, similar traces were recorded. The records were, it must be admitted, rare and the probability was set as once per 6×10^5 km^2 nights.

However, Dr. Tompkins also indicated in correspondence to this author that the traces were not totally consistent and the interpretation not totally definite. They did not reflect the characteristics of lightning strokes yet do not reflect complete (and without question) agreement with the bead or ball lightning interpretation.

The frame by Eriksson (1977a), Figure 5.16, is most interesting as it was video-recorded during a normal cloud-to-ground flash. A series of successive video frames were reproduced photographically, and the ball image appears in four. The illuminated ball appears to form near

the cloud at a height of about 300 m. It was not reported near the ground as would be expected of a normal ball lightning. Its duration was only 20–40 msec rather than about 1 sec. It was also thought to have appeared during intrastroke periods rather than during the periods of maximum current flow. This may be suggestive of a localized excitation of molecular metastable energy levels with subsequent decay and visible radiation due to the decreased luminosity of the discharge channel.

It may be postulated that the Eriksson (1977a) photographs represent the formation of a ball lightning that did not descend to a lower altitude where it would have a longer duration. It may well be that the most common ball lightnings are similar to those represented in the Eriksson photographs, but are never observed with the unaided eye. The phenomena observed near the ground may represent the extreme of the event, while those at a high altitude occur more frequently.

However, as one must coldly evaluate the factual evidence, it is doubtful whether even one of the three photographs may be considered as definitely that of a natural ball lightning. More corroborative and supportive data are necessary.

If one accepts the photographs as representative of the natural ball lightning event, the properties that may be deduced are rather vague. It would appear that the formation source is an abnormal lightning channel, the phenomenon has a density slightly greater than that of air, and it may have a variable intensity. Its diameter is less than a meter.

Many of the photographs and reproductions listed in Table 6.3, which were identified as being artificially produced ball lightning, are also clearly erroneous. The photographs by Plante (1884b,c), Figure 7.5, and Plante (1885a), Figure 7.6, are now recognized as being related to small-scale direct-current discharge phenomena. The photograph of Trowbridge (1907), Figure 5.36, is representative of the low-pressure discharge illuminations similar to those of Loeb and Kip (1939), Figure 5.37, which were not identified as being of ball lightning. The photograph by Ritchie (1963), Figure 5.40, is a low-pressure discharge phenomenon, similar to that by Hatch (1958), Figure 5.39. Neither photograph was originally identified as that of a ball lightning.

Two important criteria must be satisfied by artificial ball lightning: the phenomenon must occur at atmospheric pressure, and it must remain after the power source has been terminated. There are three known examples that satisfy the criteria.

The photograph by Barry (1966), Figure 7.11, illustrated that a low-density hydrocarbon combustion process may produce a persistent

luminous phenomenon at atmospheric pressure. However, it was also recognized by Barry (1968a,c) that the hydrocarbon density in air required by the process was far greater than that normally found in nature. Consequently, the process must have a low probability of occurrence unless some mechanism operates to locally increase the density of hydrocarbons to a level where low-density combustion could be supported.

The photographs by W. Brand (1923), Figures 5.22 and 5.23, were produced repeatedly by high-current and high-voltage short circuits. The experiments of Silberg (1962) indicated that such processes could produce persistent luminous phenomena in the air. It is probable that vaporized electrode material was primarily responsible for the visible object and represents another means by which atmospheric luminous phenomena could be produced.

It was speculated by Hubert (1975a) that a cloud-to-ground stroke can cause volatile substances on or in the ground to become gaseous, to be excited by the energy deposited, and remain visible for a time longer than the normal lightning channel. The process could be responsible for the formation of the object photographed by Hubert (1975a), Figure 7.2. The photograph made during experiments by Powell and Finkelstein (1969), Figure 7.14, seems to support the concept.

A mass of air was caused by radiofrequency excitation to remain luminous after the localized power source had been terminated. The experiments of Powell and Finkelstein (1969, 1970) are remarkable in that normal air, undoped by any material, was used and was made to exhibit luminous behavior and other characteristics associated with ball lightning. The source of the luminosity was essentially CO_2 molecular radiation. The excitation energy was stored in the metastable states of other molecules and transferred slowly to the CO_2 molecules with subsequent radiation.

In general, then, most photographs identified as those of ball and bead lightning are erroneous. Only a few may be considered valid. It is proper that one recognize that photographs are necessary but not sufficient. Simultaneous photographs taken from two directions would be better, if available. Most often, the events occur unpredictably and the observer is unprepared. It is clear then, that the remote automatic method of Tompkins, Rodney, and Gooding (1975) and Eriksson (1977a) should be the most preferred means of ball lightning photography.

This author would request that those with photographs thought to be of ball lightning examine them critically and seek professional opinions.

7

Laboratory Ball Lightning

7.1. Introduction

The origins and sources of ball and bead lightning have stirred the imagination of scientists and laymen alike. Since many have concluded that the rare luminous forms are storm related, numerous attempts have been made to produce the phenomenon artificially. Laboratory experiments have been conducted with natural electrical sources as well as artificial electrical machines. Early 17th century investigators attempted to utilize atmospheric electricity and natural lightning to evaluate the electrical phenomenon thereby generated. Since then, the development of batteries, induction machines, high-voltage power supplies, and radiofrequency generators has enabled the scientist to generate electrical phenomena in the laboratory under reproducible conditions. It is the desire and need of the scientist to produce a phenomenon at will for study that enables a theory or set of assumptions to be tested in a systematic and unbiased manner. A scientist cannot be satisfied with a paper and pen model which can never be critically examined in an experimental manner.

The presently existing concepts and models proposed to explain ball and bead lightning are considered to be preliminary. Electrical phenomena with ball lightning appearance have been produced in the laboratory, yet none possess all of the reported characteristics of the natural event. Even though the experimental attempts have not been entirely satisfying, the experiments and the results have been quite instructive. We must recognize that the important aspect is the resulting phenomenon, not necessarily the means of production.

We do have extensive data on laboratory phenomena that exhibit many of the important characteristics of the natural event. Study of these phenomena has allowed the evolution of our knowledge. It is

certain that future experiments will be able to exploit these past experiments and further our present understanding. It is still true that our knowledge of the natural origin, phases of development, behavioral influences, sources of energy, continued existence, and decay processes of natural ball and bead lightning remains somewhat speculative.

The unbiased evaluation of laboratory experiments conducted to investigate ball and bead lightning production is admittedly difficult. One has expectations regarding the direction and end result of the research, and it is hard to overcome preresult biases. The results could be viewed in several ways depending upon the mind and judgment of the evaluator. The experimenter in ball and bead lightning research has several problems; first, little is definitely known about the physics of the natural phenomena, and second, many laboratory-produced phenomena may visibly resemble the natural events, yet do not present conclusive evidence regarding their stability or their formation process. The main criteria for acceptable formation is the production of a stable, persistent, localized luminosity in air at atmospheric pressure which remains for some finite measurable period after the termination of the source energy.

Serious laboratory experimentation with ball lightning has been undertaken only within the last century or so. This should not be too surprising since adequate equipment and technical knowledge was unavailable prior to the mid-18th century. The earliest recorded work on ball lightning may have been accidentally performed in the mid-17th century by Professor Richmann of St. Petersburg using natural lightning. The earliest laboratory work was apparently performed a century later by du Moncel (1853). Progress in electrical equipment and understanding of electrical phenomenon encouraged further attempts in the late 1800s by Hertz (1883), Hesehus (1901), Indrikson (1900a,b), Leduc (1899a), von Lepel (1890c), Piltschikoff as described by Anon (1900f), Plante (1875b—1890), and Toepler (1897, 1900a,c). Advancements in general technology lead to further studies in this century as well: Babat (1947); Barry (1966, 1967a,b, 1968a,c); Fehr (1963); Nauer (1953, 1956); Powell and Finkelstein (1969, 1970); and Ritchie (1963). These laboratory experiments have been extensively discussed and debated.

In order to more easily evaluate the experimental laboratory results, the area of experimental work has been divided here into four types according to the experimental method. These areas of investigation include the following. *Type 1:* The use of natural lightning in the attempt to produce a luminous phenomenon for study in a controlled manner. *Type 2:* The use of an electric discharge in a gaseous atmosphere

to produce a luminous combustion phenomenon. *Type 3:* The use of an electric discharge through a solid conductor to produce a luminous metal vapor phenomenon in the atmosphere. *Type 4:* The use of a focused radiofrequency discharge in a controlled atmosphere to produce a luminous and persistent phenomenon.

It will soon become clear that ball-lightning-like phenomena may be produced with a variety of experimental methods. The resulting phenomena all exhibit some of the reported characteristics of the natural phenomena. The major differences between experimental methods is not necessarily the result produced, but rather the manner employed to produce a localized volume with an energy content greater than that of normal air. Based upon the present results of laboratory experiments, it would appear that natural ball lightning may be not one phenomenon but many, each with similar appearance but with different mechanisms of origin, different stability criteria, and somewhat different properties dependent upon the atmosphere and the environment present at the time of the event.

7.2. *Type 1: Use of Natural Lightning*

Since ball lightning is most commonly associated with lightning and thunderstorms, it was only natural for early scientists to attempt to harness atmospheric lightning for laboratory experiments. The first recorded scientific investigation of a reportedly ball lightning-like phenomenon has been attributed by Chirvinsky (1954), Eliseev (1941), Leonov (1965), Menshutkin (1952), and Powell and Finkelstein (1969, 1970) to a Dr. Richmann of St. Petersburg in 1753. The ball-lightning-like discharge was supposedly produced accidently during a thunderstorm. The incident has become quite well known throughout the circles of those interested in the investigation of lightning and ball lightning phenomena. This is not so much for the experimental attempts but rather because a ball lightning was reported to have struck Dr. Richmann in the forehead, causing his death on the 6th of August 1753.

The events surrounding the accident were discussed by Watson (1754) and Anon (1755) based on information received from Russia, and later by Hare (1828), Figuier (1870, 1884), Flammarion (1874), Eliseev (1941), Chirvinsky (1949), Menshutkin (1952), Leonov (1965), Mendenhall (1890), and by Powell and Finkelstein (1969, 1970). The report by Watson (1754) was based upon a translation of a report by a Professor Winkler of Leipzig, which, in turn, was apparently obtained from another report by a Professor Heinius of Leipzig. Another

discussion of the incident by Mr. Lomonosov (1753) of the Royal Academy of Sciences of St. Petersburg was mentioned by Watson (1754) and by Leonov (1965), but the original was not available to this author. The experimental apparatus has been discussed in some detail with figures and dimensions by Watson (1754), Anon (1755), and later by Hare (1828), Eliseev (1941), Menshutkin (1952), and Leonov (1965). Anon (1755) even reported on the autopsy of Dr. Richmann.

The Richmann experimental device essentially consisted of a ungrounded lightning rod upon the laboratory roof, which was connected by isolated metal conductors to an electrometer in the laboratory. The experiments with lightning were designed to measure, in a relative manner, the charge accumulated by suspended repelling threads. The charge was collected by the lightning rod from the electrified atmosphere during thunderstorms. It was not necessary nor intended that lightning strike the metal rod, but that is apparently what occurred.

The basic experiment inadvertently conducted by Dr. Richmann was the discharge of intense electrical energy across an air gap. We may assume that since the ungrounded lightning rod used by Richmann did in fact attract a reportedly intense natural lightning discharge, that an induced high-current atmospheric discharge was created within Richmann's laboratory between the metallic terminals of the air gap. The report by Watson (1754) states that the atmosphere content was essentially that of the air in the immediate environment; that is, no specific contaminants were purposely introduced for experimental reasons.

The experiment was observed by Mr. Sokolov, engraver to the Royal Academy at St. Petersburg. Watson (1754), Menshutkin (1952), and Leonov (1965) reported that Mr. Sokolov saw a blue-white globe of fire as large as his fist pass from the metal rod of the electrometer to the forehead of Dr. Richmann. A woodcut illustrating the Richmann accident was made soon after 1753, apparently published originally by Figuier (1870, 1884), reproduced later by Elissev (1941), by Powell and Finkelstein (1969, 1970), by Singer (1971, 1977), and by Viemeister (1961), and shown here in Figure 7.1. It is this woodcut and the interpretations of Chirvinsky (1949), Leonov (1965), and Powell and Finkelstein (1969, 1970) that have popularized the concept that the death of Dr. Richmann was caused by a ball lightning. An illustration similar to that in Figure 7.1 but showing Richmann on the floor was published by Flammarion (1874) and later by Dibner (1977).

However, careful examination of the available evidence, specifically the reports by Watson (1754) and Anon (1755), suggests that a ball-lightning-like phenomenon may not have occurred at all. Anon (1755) reported that Mr. Sokolov observed a great blue and white fire pass

Figure 7.1. Photograph of a woodcut illustrating the accidental death of Dr. Richmann in St. Petersburg in 1753. reportedly by a ball lightning. The ball lightning is thought to have developed from the experimental apparatus used to measure the electrification of storm clouds. Reproduced with the permission of Dr. Powell and Academic Press. The woodcut was originally published by L. Figuier, *Les Grandes Inventions,* Paris, 1870. This print or slight variations thereof have been reproduced by C. Flammarion, *The Atmosphere,* Haper and Brothers, J. Glaisher, Ed., New York, 1874; by L. Figuire, *Meraviglie e Conquiste della Scienze l'elettricita e le sue Applicozioni,* Milan, 1884; by A. A. Elissev, *M. B. Lomonosov,* Leningrad, 1941; by P. E. Viemeister, *The Lightning Book,* Doubleday and Co., New York, 1961; by J. R. Powell and D. Finkelstein, "Structure of Ball Lightning," in *Advances in Geophysics,* H. E. Landsberg and J. Van Mieghem, Ed., Academic Press, New York, Vol. 13, 1969, p. 141; by J. R. Powell and D. Finkelstein, "Ball Lightning," *American Scientist,* **58,** 1970, p. 262; by S. Singer, *The Nature of Ball Lightning,* Plenum Press, New York, 1971; and by B. Dibner, "Benjamin Franklin," *Lightning,* R. H. Golde, Ed., Academic Press, Vol. 1, 1977, p. 47.

between the metal rod of the electrometer and Dr. Richmann's head. He also noted that a globular flame was commonly produced at the air gap by natural and artificial electricity discharging through the apparatus. This is in contrast to the blue-white globe of fire reported by Watson (1754). Anon (1755) also gave much more detail on the damage to the room and house than available in Watson (1754). Anon (1755) also reported on the attempted revival of Dr. Watson and the subsequent postmortem examination.

Both Watson (1754) and Anon (1755) concluded that Dr. Richmann had been killed by the electrical discharge. Neither made a specific issue of the shape or appearance of the observed discharge. Hare (1828) made no reference to the globe of fire and discussed the death as a result of the lightning strike. The postmortem examination reported by Anon (1755) indicates that the observed body damage was associated with the passage of electricity rather than contact with a hot ball. Additionally, overall electrical neutrality or near electrical neutrality must be assumed for a ball lightning. Based upon the evidence available, we must conclude that Dr. Richmann was electrocuted and not killed by a ball lightning. It is unfortunate that many specific details of the Richmann accident are no longer available.

It is interesting that the evolution of experiments with atmospheric electricity in general and ball lightning in particular have moved from using natural lightning discharges to producing discharges on a small scale within the laboratory by artificial means. However, in spite of modern developments, or rather, because of modern developments, recent ball lightning experimentation and investigation have returned to utilizing the natural lightning discharge. Since control of natural atmospheric charge concentrations and lightning discharges is extremely unlikely, investigators have used new concepts. Lightning discharge stimulation has become possible and may be controlled, to some extent.

The deliberate triggering of lightning was first demonstrated by Newman, Stahman, Robb, Lewis, Martin, and Zinn (1967) and later by Newman (1968) at sea. Small rockets were launched into storm clouds and provided a discharge path by means of a thin metal wire, one end carried by the rocket and the other connected to the ground. The experiments were conducted from a ship, which allowed a fine degree of mobility for the experiments. Triggered lightning discharges could then be controlled and caused to occur as desired from naturally occurring concentrations.

Similar experiments were conducted on land by Fieux, Gary, and Hubert (1975). Rockets were launched from the top of a metal tower 24 m high. A 0.2-mm metal wire unwound from a reel mounted on the

tower or on a shorter pillar near the tower. The rocket pulled the wire to a height of some 700 m in about 5 sec. The rocket was normally destroyed at peak altitude for safety reasons. The wire provided the conduction path for the high-current discharge and was itself evaporated in the process. The triggered lightning appeared to be similar to upward natural lightning striking tall structures. The triggered lightning began with a relatively slow discharge. The current was in the kiloampere range for a few tenths of a second. The upward discharge speed was about 2×10^4 m sec^{-1} for negatively charged clouds and over 5 times greater for positively charged clouds.

Photographic analysis of the triggered discharges have been produced by Hubert (1975a), Fieux, Gary, and Hubert (1975) and Fieux and Hubert (1976). The photographs were made with movie film (48–150 frames per second) and with single-frame still film. It was found upon evaluation of the films that many of the triggered lightning channels had a beaded appearance during decay. The beaded appearance was more apparent with increasing lightning current. The individual illuminated beads had a diameter of about 40 cm and a persistence of about 0.3 sec. A photographic example of one of these discharges was shown in Figure 2.11.

It was found that with an initially straight channel which adopted a progressively more tortuous shape, luminous beads occurred where the degree of channel stress was greatest. This suggests that the beads occur at channel bends, supporting the suggestions of Lowke, Uman, and Lieberman (1969). A positive correlation existed between beam diameter and lifetime.

In addition to the observation of beaded structures, one or two luminous balls were observed to occasionally remain near the ground at the conclusion of a channel decay. These luminous balls had an upward motion of 1–2 m sec^{-1}, suggestive of a density lower than that of the surrounding air. It was also observed that a luminous bead would remain undisturbed and apparently stable even as a subsequent strike discharged nearby. This suggests that the luminous beads do not result from a persistent current in the original channel as such a current would be disturbed by a nearby discharge. A photograph of the persistent luminous bead near the ground is shown in Figure 7.2.

It would also appear that the luminous beads are not a result of the residue of the vaporized metal wire. As the discharge occurred, the wire was first severed at the lower end near the reel where the greatest stress was on the wire. The wire was then carried upward by the final rocket motion leaving an air gap of a few meters near the ground. After complete air ionization, the current flow increased and the lower

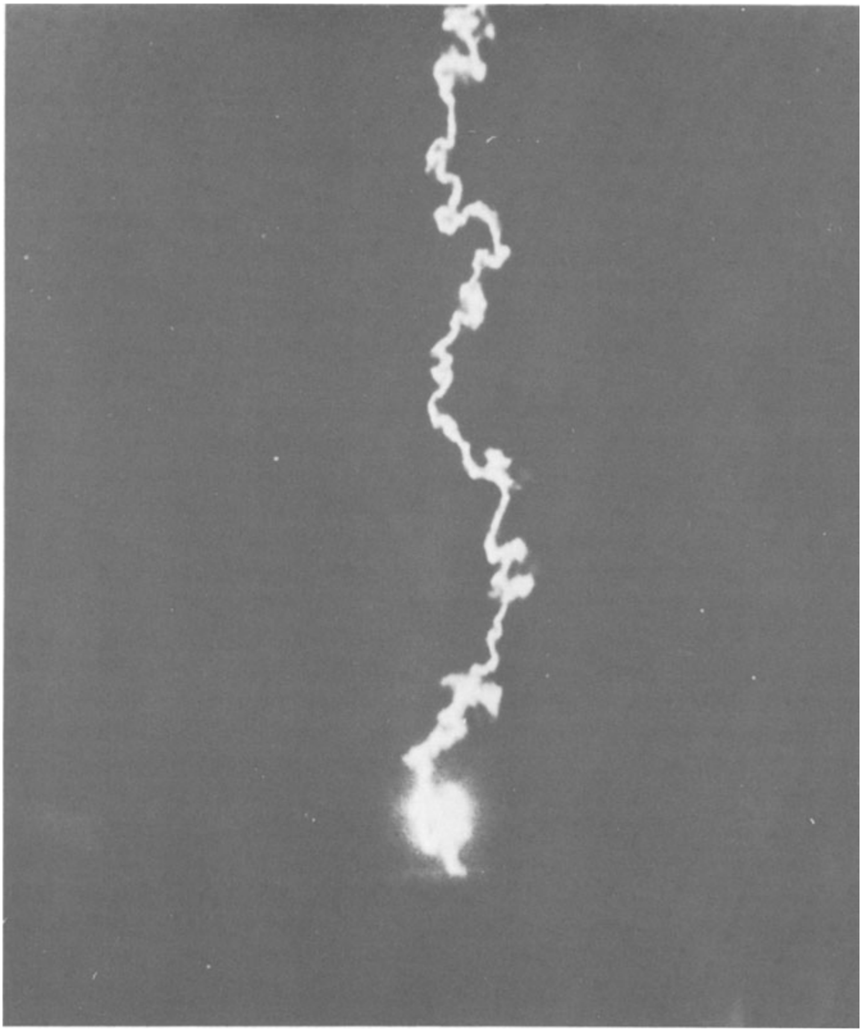

Figure 7.2. Movie camera photograph of the persistent illumination which could be caused to remain near the ground after a triggered cloud-to-ground lightning stroke. The luminous object near the ground would occasionally remain after the main channel luminosity decayed and would rise upward with a velocity of 1–2 m sec^{-1}. Reproduced with the permission of P. Hubert and C. E. N., France, after P. Hubert, "Tentative Pour Observer la Foudre en Boule dans la Voisinage d'Eclairs Declenches Artificiellement," Rapport DPH/EP/76/349, 5 Mai 1975, Commissariat à l'Energie Atomique, Service d'Electronique Physique, Center d'Etudes Nucléaires de Saclay, France.

few meters of the channel initially emitted less light than the upper part. This difference disappeared early during the channel afterflow. The bead formation occurred in the lower portion of the channel where no wire existed as well as in the upper portion where wire existed.

Other experiments were conducted with triggered lightning strikes to wooden posts and soot-laden pipes on the ground. Localized single luminous ball phenomena were observed to last after the channel disappeared. The ball luminosity appeared stationary and had a diameter of about 25 cm. It was suggested by Fieux, Gary, and Hubert (1975) that the illuminated balls resulted from the intense electric currents circulating in the ground at the base of the discharge channel. In a manner similar to that by Trecul (1881), it was speculated that ground heating could supply hot gases to produce the light emission. Whether the hot gases were from normal air heated to a relatively high level, or from hydrocarbons liberated to become involved in a combustion process, or from hot air seeded with surface contamination is not known at this time. A photograph showing this ground-lightning strike phenomena and its development is shown in Figure 7.3. A similar concept for the formation due to the evolution of solid (that is, gas) material from the point of a lightning strike was discussed by Andrianov and Sinitsyn (1977).

Unintentional triggering of lightning discharge to an underwater explosion plume was reported and discussed by G. A. Young (1962). Naval experiments were conducted in 1957 in Chesapeake Bay to study the phenomena associated with the explosion of underwater mines and depth charges. During one test, lightning struck the central portion of a water plume when the plume was at an altitude of about 75 m above the surface of the bay.

Two cameras were used to study the plume structure from a distance. Each recorded the lightning strike. Four separate discharges were detected. All strokes apparently followed the same path and occurred before the preceding strike luminosity decayed. The most interesting effect was the appearance of a bead structure as the discharge luminosity faded. Refer to Figure 2.10.

It is clear that bead-lightning-like and ball-lightning-like phenomena may be produced as desired for evaluation and study. The triggered lightning technique promises to be one of the most powerful tools available to scientists interested in bead and ball lightning study. The phenomena may be produced repeatedly as needed for scientific and critical examination. Since this technique utilizes the natural event, which may be induced to occur when, where, and as the experimenter desires but limited to natural charge concentration conditions, it has

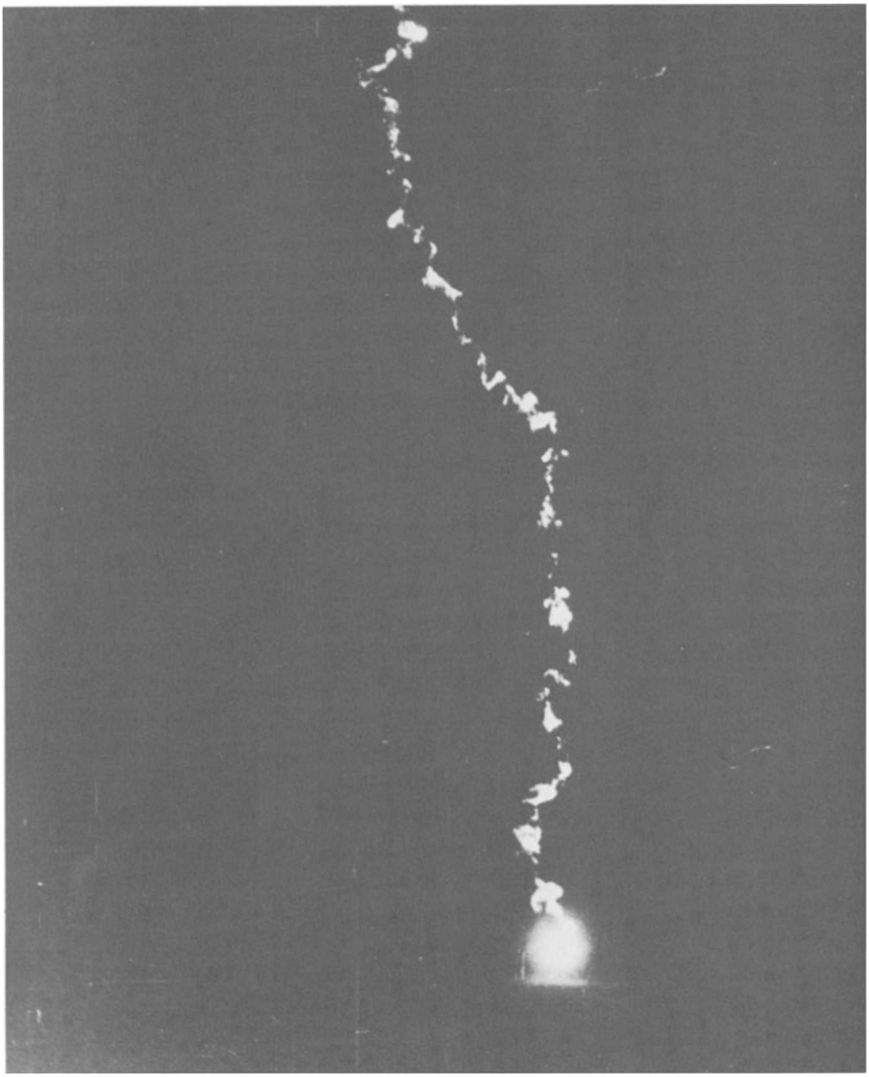

Figure 7.3. Movie camera photograph sequence of the persistent illumination caused to occur with some triggered lightning strokes which terminated to grounded objects. It is speculated that ground gases, heated by the current flow, could be the source of the illumination. Reproduced with the permission of P. Hubert and Center d'Etudes Nucléaires, France, after P. Hubert, "Tentative pour Observer la Foudre en Boule dans la Voisinage d'Eclairs Declenches Artificiellement," Rapport DPH/EP/76/349, 5 Mai 1975, Commissariat à l'Energie Atomique, Service d'Electronique Physique, Center d'Études Nucleaires de Saclay, France.

advantages over artificial ball and bead lightning within the laboratory. Most important is the availability of intense currents and large charge dissipation. The luminous phenomena may be studied in the natural environment or in an environment modified to some limited degree for specific experimental purposes.

7.3. Type 2: Gaseous Electrical Discharge

The identification of ball lightning and bead lightning (as *éclairs en boule*) as one of the three forms of lightning by F. Arago (1838), effectively established the accepted scientific position that both were related to natural atmospheric electricity. Such was the stature of Arago at that time. du Moncel (1853), a Deputy of the French Academy of Science, later included four classes of lightning discharge, but still allowed ball lightning forms, including the corona discharge, St. Elmo's Fire, to be identified with atmospheric electricity. Consequently, it was only natural for those in the theoretical and experimental areas to relate the new physics of electricity to these phenomena.

There were those, however, notably M. Faraday (1839), who were convinced that ball lightning is not related to an electrical discharge. Rather, they attributed its appearance to retina retention of a nearby lightning discharge as later argued by von Schiodt (1893). There was, as has occurred repeatedly since, intense conflict between scientists of the period, and serious investigation of the ball lightning phenomenon may have suffered. The history of these affairs and occurrences of the early period of electrical research has been documented by de Jans in a series of papers from 1910 to 1912.

Laboratory investigations of the electrical phenomena could not have begun prior to the introduction of the Leyden jar in 1745. The Leyden jar or phial, as usually made, consisted of a wide-mouth glass jar or other suitable dielectric container with the inner and outer surfaces covered by a thin metal layer to within a few inches of the top. An illustration is shown in Figure 7.4. The mouth of the jar was normally closed by a wooden or cork stopper, through which passed a metal wire or rod, the lower part making contact with the inner metal foil. The upper portion of the wire or rod terminated in a small metallic ball. The device was a simple capacitor: two conducting elements separated by a nonconductor.

The discovery of the Leyden jar has been individually accredited to an experimenter named Cuneus, a monk named Kleist, and a Professor Muschenbroeck of Leyden. Watson (1754) referred to the

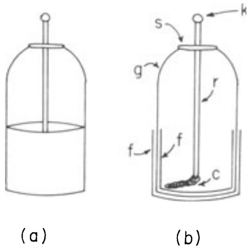

Figure 7.4. Schematic drawing of a Leyden jar; (a) shows a side view and (b) shows a vertical cross section. The jar is essentially an insulating container, such as glass (g), the lower section covered inside and out by a metal conducting foil (f), a conducting contact from the inner foil to an upper knob achieved by a metal rod (r), chain (c) and knob (k), and covered by a stopper (s).

device as being from Professor Muschenbroeck. The Muschenbroeck phial was originally filled with water, which acted as the inner conductor, and the outer conductor was the moist hand of the experimenter. It was charged by touching one conductor to the electrical source, the other being grounded. The metal foil was reportedly added by Sir W. Watson soon after its display in Leyden. The metal foil vessel could be charged by frictional means or by accumulation of static electricity. A relatively high-voltage spark could be obtained upon discharge of the Leyden jar capacitor.

A number of early scientists investigated the discharge characteristics of the Leyden jar. The early history of electrical experiments is somewhat vague with regard to the description of experiments. It would appear that early experiments with Leyden jar discharges were made by two English physicists, Arden and Constable, in the late 1700s. They caused a powerful charge to be accumulated in a Leyden jar and observed a small fireball illumination at the point of the discharge. The small fireball illumination was about one-fourth of an inch in diameter, was red in color, had rapid random motion, and terminated with a loud explosion. Bertholon (1787) discussed the Leyden jar experiments of Arden and Constable and described the results as being analogous to the observation of meteors and atmospheric electricity.

A report on Leyden jar experiments with various liquids and gases was made by Van Marum (1795) and discussed by Anon (1800). The results of discharge experiments with Leyden jars were compared to natural lightning by Joule (1850).

It was not until the mid-19th century, when physicists had more equipment, that serious analogies between ball lightning and electrical

discharges were made. An intense electrical spark from a high-voltage coil, termed a Rumkorff machine, was caused by du Moncel (1854a,c) to discharge between a metal electrode and a flat surface which was covered by a liquid, usually water. A luminous red spherical discharge was observed. It was noted that the flame and spherical discharges were more intense when the liquid was present. Dry air did not produce the same spectacular results as did moist air. du Moncel suggested that the high-voltage spark experiment was analogous to the conditions in nature during most ball lightning observations. Namely, an electrified cloud, a moist atmosphere, a flat, moist, conducting earth, combined with a cloud-to-earth lightning discharge gives rise to ball lightning.

There were a number of other scientists at that time who also discussed the apparent similarity between the spark experiments and the natural event. That the discharges appeared to be luminous, spherically shaped, highly mobile, dependent upon the presence of moisture, and yellow or red in color was quite sufficient for many. Poey (1855) revived the earlier concepts of Arago that ball lightning was a pure lightning discharge form, that is, a distinctive spheroidal state. Others considered ball lightning as a result of a normal discharge, that is, resulting from its action on the atmospheric medium. Supporters of the coil and Leyden jar discharge concept included many notable experimenters, such as Joule (1850), de la Rive (1858), de Tessan (1859), Faye (1877), and Tait (1880c). In addition, Anon (1890c) reported that Professor Cavallo observed a luminous ball of fire ascend from a highly charged Leyden jar and decay explosively.

Investigation into natural electrical events, with laboratory discharge means, improved with the progress in available equipment. Experiments with capacitor discharge techniques gained popularity during the mid to late 19th century. The relationships between direct current discharges under various conditions at atmospheric pressure were reported in the works of Plante from 1875 to 1890. Plante (1877b,d; 1878b) discussed the fabrication and operation of his *machine rheostatique*, which was used during some experiments to produce an intense electrical charge. The experimental efforts of Plante have been discussed by many of his contemporary scientists such as de Jans (1911a–c, 1912a–c), Sauter (1895, 1896), Weber (1885e), and later by Leonov (1965). It was widely assumed at the time that Plante's work demonstrated a laboratory-produced ball lightning.

The basic technique was the controlled discharge between parallel plates. Plante was encouraged by the previous success with the Leyden jar and essentially extended the technique using equipment not available earlier. The parallel plate capacitor, of course, is just the result of

development and optimization of the early Leyden jar. Plante made observations with two parallel flat metal sheets separated by a thin mica sheet, The capacitor was connected across the poles of a number of storage batteries providing about 4000 V. The discharge formed as the mica sheet was pierced at a weak point. A small incandescent globule was formed at the point of the discharge, apparently by evaporating portions of the capacitor. The experiment lasted only a few minutes until the battery was exhausted and could no longer support the discharge. The luminous globule appeared to move about the surface of the plates in a random wandering motion. The discharge was also accompanied by a crackling noise.

Plante proceeded with experiments which were thought to more closely duplicate atmospheric conditions. The metal and mica of the capacitor were replaced with damp surfaces separated by an air gap. The damp surfaces were formed by pads or filter paper disks moistened with distilled water. When the pads were connected across the capacitor and battery poles, a small ball-of-fire discharge formed between the two surfaces. The ball of fire occurred between moist areas and would not occur between dry areas. The discharge moved about the surfaces randomly but remained between damp areas. The ball-of-fire discharge would continue between the damp surfaces until the voltage source could no longer support the discharge. Plante speculated that the discharge caused the evaporation of the water, which aided in the current discharge between the two surfaces. An illustration of the results is shown by the drawing in Figure 7.5. The photograph was also published by Plante (1884b, 1885a) and Weber (1885e).

Experiments were also conducted between pointed metal electrodes and a dish filled with water. The metal rods were 60 cm in length and 10 mm thick. Various materials were also used: copper, brass, iron, and coal carbon. The voltage was derived from a number of storage batteries. Discharges were observed to occur as the distance between the electrode tip and water surface was decreased. Plante normally kept the water negatively charged. A ball-shaped discharge was observed to form near the water. This is illustrated by the drawing shown in Figure 7.6 by Plante (1877c) and reproduced by Weber (1885e). The ball was brightly colored and moved about the water surface in an apparently random manner. The color and intensity could be modified by varying the electrode material and applied voltage.

Plante specifically related the experimental results to natural ball lightning. The experiments were widely accepted at that time as being definitely related to the natural phenomenon. That is to say, ball lightning was seen as predominantly related to electrical thunderstorm

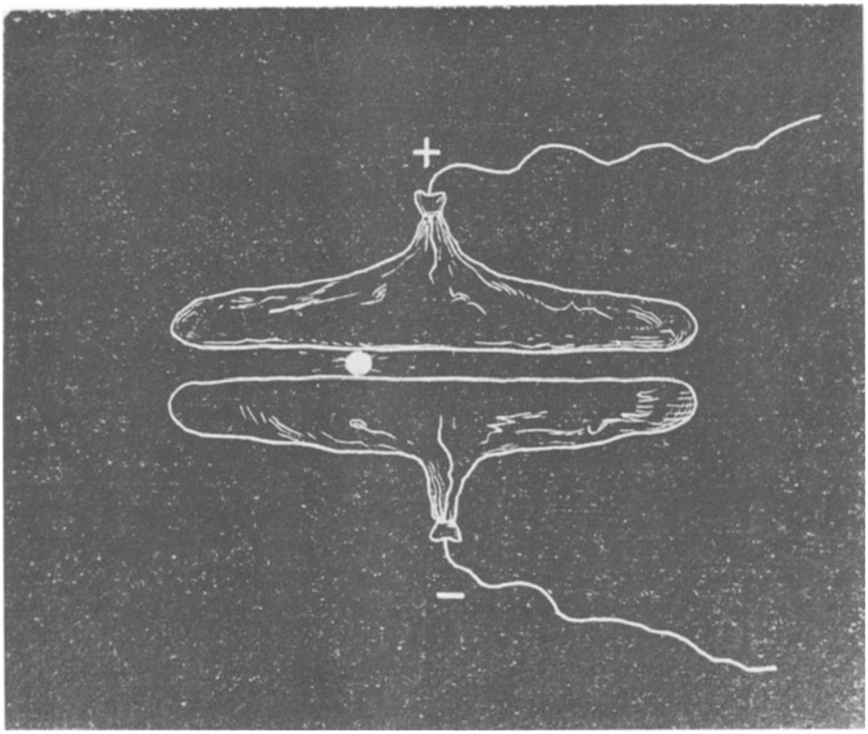

Figure 7.5. Drawing illustrating the illuminated discharge between two plates of a condensor at a high voltage. Reprinted with permission of the Academy of Science, Paris, France, from G. Plante, "Sur le Foudre Globulaire," *C. R. Hebd. Seances Acad. Sci.*, **99,** 1884, p. 273 and also published by G. Plante, "On Globe Lightning," *Electrician,* **13,** 1884, p. 366 and *Electrician,* **14,** 1885, p. 433, and by L. Weber, "Ueber den Gegenwartigen Stand der Kugelblitz-Frage," *Meteorol. Zeit.,* **2,** 1885, p. 118.

activity. This view effectively shaped considerations regarding ball lightning for decades. Ball lightning was considered to be a direct result of the electrification of the atmosphere and directly related to discharge processes under admittedly poorly understood and rarely occurring conditions.

The interpretations of Plante's experimental results were not without criticism. Most notable was that by Renou (1876) and Weber (1885e), who could not accept the speculation that natural atmospheric electric fields would discharge in the manner suggested by Plante. Weber considered the reported similarity between nature and experiment to be misinterpretation based upon conditions assumed prior to the experiment. However, the discharge experimentation continued,

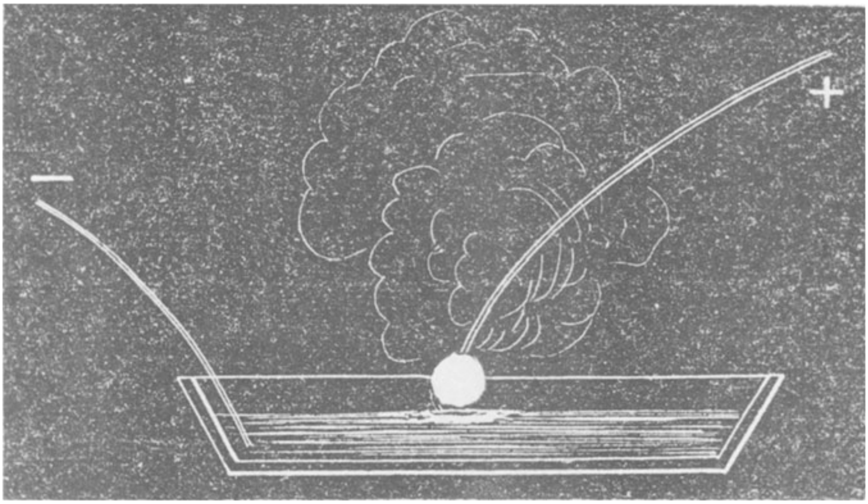

Figure 7.6. Drawing illustrating an illuminated direct current discharge at atmospheric pressure occurring at a liquid surface which acts as the negative electrode and a thin metal rod acting as the positive electrode. Reproduced with permission of the Academy of Science, Paris, France from G. Plante, "Suite de Recherches sur les Effets Produits par des Courants Electriques de Haute Tension, et sur Leurs Analogies avec les Phenomenes Naturels," *C. R. Hebd. Seances Acad. Sci.*, **85,** 1877, p. 619, and by L. Weber, "Ueber den Gegenwartigen Stand der Kugelblitz-Frage," *Meteorol. Zeit.*, **2,** 1885, p. 118.

for example, with high-voltage induction techniques by von Lepel (1889, 1890a,c). These experiments have also been discussed by Sauter (1895, 1896).

Van Lepel caused a high-voltage discharge to occur between a cylindrical electrode and a flat plate electrode with a separation of about 6–8 cm. The discharge appeared as a small blue-red illuminated sphere with a diameter of about 0.05 cm and had a rapid and random motion. Experiments were also conducted with paraffin, water, or salt water placed on the flat plate. Chemicals, such as barium chloride and strontium chloride, were also added. The discharge diameter varied somewhat, and other colored spheres could be produced, alternating among red, yellow, green, and white.

Piltschikoff, according to Anon (1900b), conducted similar experiments with an induction coil source and varied the discharge atmosphere by placing turpentine on the metal plate. A ball of fire was again produced. It will become apparent later in this chapter that the influence of a hydrocarbon in the atmosphere can affect the discharge charac-

teristics. Piltschikoff was apparently the first to experimentally modify the atmosphere by the presence of a hydrocarbon. Hildebrandsson (1885) was apparently the first to suggest a relationship between explosive (hydrocarbon) gases and the production of a ball lightning phenomenon.

Many similar experiments were conducted in the latter 1800s. Baljasni (1899a) produced illuminated discharge spheres above water surfaces with a high-voltage coil as the source. Hesehus (1901) extended the experiment technique of Plante and used a transformer to produce a 10^4-V alternating current source. A copper plate and a water surface with a separation of 2–4 cm were used as electrodes. Rays, ball of fire, flames, conical, oval, and spherical forms and images were produced, similar to those produced by Plante (1877b).

Mobility, color changes with the applied voltage, and a sharp ozone or saltpeter odor were observed. It was deduced by Hesehus (1901) from examination of the gaseous products that oxides of nitrogen were formed. Hesehus suggested that the ball lightning formation and existence was related to nitrogen combustion.

Other experiments were not as clearly related to the ball lightning phenomenon. Leduc (1899a) measured the motion of an experimentally produced, illuminated electrical discharge. Indrikson (1900a,b) also produced glowing discharges. Both Indrikson and Leduc used a photographic plate as one pole to trace the path and discharge characteristics of the discharge. The concentration of Ag particles indicated the discharge path of the moving spark.

The experiments of I. Galli (1909 to 1912) were mentioned numerous times by scientists near the turn of the century. De Jans (1910, 1911, 1912) discussed the results of the discharge experimentation and the similarity to natural ball lightning. The apparently important works of I. Galli have not been available to this author.

The experimental works of A. Righi have also been discussed as producing laboratory examples of ball lightning. Trowbridge (1907) published photographs of the discharge phenomena reportedly similar to those produced by Righi, as shown in Figure 5.36. Illuminated phenomena were produced by causing a high-voltage discharge to occur within a partially evacuated gas cell.

High-voltage glow discharge phenomena such as these are now known to represent electric discharge conditions in rarefied media. However, such phenomena are quite different at atmospheric pressure. One may certainly speculate that natural ball lightning is related to a high-voltage discharge. However, to use low-pressure experiments for

support is not entirely satisfying. Experiments should be carried out at atmospheric pressure in order to more realistically duplicate the conditions associated with the appearance of ball lightning.

It should be recognized that these various experiments did not produce an independent, self-contained, luminous phenomenon. The discharges were temporary discharge phenomena and depended upon the continuation of the discharge for their continued existence. This does not mean, however, that some similar type of discharge could not occur in nature and be classified as a ball lightning event. However, the relationship of such discharges to ball lightning has been somewhat questionable.

The investigation of discharge experiments is often complicated by the lack of definitive published results. King (1976b), for example, proposed atmospheric pressure Tesla coil discharge experiments in moist air vortex currents, possibly reflecting the thoughts of Vonnegut (1960). The experimental results are not known to this author. In addition, Iur'ev (1961) discussed discharge experiments in air within nonconducting cylinders. The data presented were too brief to allow definitive comment.

Exhaustive experiments were conducted in the mid-1950s in order to evaluate the origin of ball lightning and bead lightning and to define a representative model for the phenomena. Nauer (1953, 1956) duplicated in a generic fashion most of the earlier experiments and evaluated the results with respect to electric discharge and plasma theory. Additionally, he evaluated new techniques with outstanding success. It was Nauer's opinion that the similarity between certain discharges and the reported properties of ball lightning grows tenuous and vague when examined in a critical manner. He concluded that even though luminous discharge phenomena with some resemblance to ball lightning could be produced, no single independent luminous mass with all the characteristics of ball lightning had ever been produced.

Nauer initially used a pointed metal electrode placed above a water surface with the discharge caused to occur between the two in attempts to duplicate and study the results of Plante. The separation distance was 2–14 mm, discharge voltages were 500–1500 V, and the discharge current was 20–250 mA. Different results were obtained with positively and negatively charged metal electrodes.

The discharge arc was quasispherical when the pointed electrode was negatively charged. The sphere appeared to be composed of a number of different colored and highly luminous spherical shells. The brightest spot was located just below the electrode tip and the underside

of the sphere was penetrated by many blue-violet filaments. Similar drawings were made by Plante (1877b).

When the pointed electrode was positively charged, a ball-of-fire discharge appeared. The arc again consisted of separate luminous shells and lower filaments. However, the filaments formed a cone above the water surface and appeared to penetrate the whole ball. The color of the discharge could be changed by the electrode material, and the intensity increased with discharge current. Similar discharge arcs were obtained in the manner of Plante when both electrodes were damp paper pads. The discharge was highly mobile and bright orange in color.

Nauer also repeated the experiments of Hesehus, which may be considered to be the alternating current analog of Plante's direct current experiments. The resulting discharge appeared to be a superposition of the two earlier direct current results with positive and/or negative metal electrodes and a water surface. It was observed that spherical discharges were easier to obtain with a metal plate rather than with the water surface. The alternating current discharge was not as mobile as the direct current counterpart. Variations in the geometry of the discharge could be produced by varying the flat electrode material. The electrical and thermal conductivity of the flat plate apparently influenced the discharge form and appearance to some degree.

All in all, Nauer's experiments repeated and substantiated the discharge results reported by Plante and others. However, Nauer did not consider the results conclusive in showing that natural events could occur in a similar fashion. He also noted that the discharges were not concentrated in a limited volume but had some form of complicated structure over the total distance between electrodes. Nauer knew of no way to model the natural event without using complicated and improbable plasma theory. He did not consider the Plante discharges to be representative of the natural phenomenon.

Nauer also attempted to model storm cloud conditions in the laboratory in order to test rainstorm theories concerning the origin of ball lightning. A sealed wooden box of dimensions 60 × 60 × 20 cm was placed on an insulating table. A metal plate electrode was placed in the bottom of the box and covered with a mixture of wet sand and gravel. Air was blown through the mixture to form bubbles above its surface. Another metal plate electrode was suspended above the surface of the wet mixture. The region between the electrodes was varied by applying warm, dry, clean, or dusty air, and observing the actions of the bubbles as a high voltage was applied across the electrodes. The

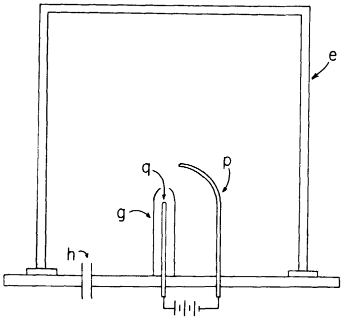

Figure 7.7. Drawing illustrating the experimental chamber used by Nauer (1956) to create discharge phenomena at atmospheric pressure in a hydrocarbon atmosphere. Glass tube (g) was partially reduced at one end and covered one electrode (q), the other electrode (p) was curved so that one end was near the glass tube hole. The apparatus was contained in a vacuum enclosure (e) created by a vacuum pump attached by means of hose (h).

bubbles were apparently affected by the static electric field. However, no luminous bubbles were observed to form.

A more productive experiment was performed by Nauer using the apparatus illustrated in Figure 7.7. A metal electrode was placed within a small glass tube of internal diameter 5–7 cm. The size of the hole in the end of the tube was varied. A second electrode was placed nearby outside the glass tube. Both were placed within a glass vessel which could be evacuated. Nauer observed that in a darkened room just after a spark occurred between the two electrodes, a luminous region appeared to rise from the upper mouth of the small glass tube. The luminous cloud could last for several seconds.

Nauer investigated the illuminated cloud phenomenon and found different results as the air pressure in the vessel was varied. At low pressures near 15 Torr (1 atm = 760 Torr), large bright clouds formed; at higher pressures, near 1 atm, smaller and darker clouds formed. Different gases were used: air oxygen, hydrogen, propane, an air–chlorine mixture, an air–benzene mixture, and argon. Colors, intensity, and cloud dimensions varied.

It is important to note that the luminous cloud could be formed in dry air at normal atmospheric pressure. In order for the cloud to form well, the hole in the end of the small glass tube which enclosed one electrode had to be quite small. The luminous cloud produced in normal 1-atm pressure air was also visible in an undarkened room, although specific details of its form could only be seen in the dark. Spectrographic evaluation of the emissions from the luminous cloud indicated the presence of hydrogen.

It was noted that the luminous cloud rose upward, apparently as a result of the heated gas from the spark discharge. A temperature increase of 15°C above the room temperature was measured by a thermometer in contact with the luminous cloud. The constriction at the end of the glass tube enclosing the electrode improved the formation of the luminous cloud. A small hole was required at atmospheric pressure in order to produce the phenomenon. An illuminated postglow vortex was also observed. Nauer dismissed the possibility that the luminous clouds were oxidation or burning phenomena since such forms could be produced in inert gases such as argon. The influence of minute amounts of solvent inadvertently left after cleaning is not definitely known.

Nauer's most significant experiments did involve combustion, however. It was accidentally discovered that minute traces of benzene left in a glass vessel after cleaning produced large luminous clouds after ignition by a spark within the vessel. The experiments were conducted in an enclosed vessel 6–8 cm in diameter and 50–200 cm in length. An electric spark was produced within the vessel between two metal electrodes. The luminous clouds appeared after the spark discharge and lasted for a period of seconds. The luminous clouds did not occupy the entire internal volume of the vessel but rather were 2–3 cm in diameter. The formation of the luminous clouds was apparently more probable when the hydrocarbon was thoroughly mixed in the enclosed volume of air.

It was found that the electrode assembly indicated in Figure 7.7 was not as effective as that illustrated in Figure 7.8. Iron electrodes, slightly bent at the tips, with an electrode separation of 5–10 mm, were found to be optimum. The iron electrode assembly was enclosed in a chamber in which the atmosphere could be controlled.

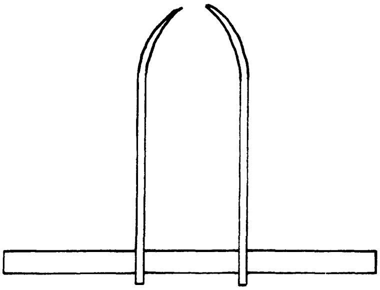

Figure 7.8. Drawing illustrating the metal electrode configuration used by Nauer (1956) to produce a controlled arc within an enclosed chamber. Electrode separation of 5–10 mm was found to be optimum.

Nauer conducted experiments at low pressures, 40–200 Torr, as well as at atmospheric pressure. At low pressures, luminous clouds were formed with as little as 3.8%–9% hydrogen gas, 1.24% propane gas, and even smaller, immeasurable quantities of benzene. It may be noted that the percentage of combustable gas required to form the luminous clouds is quite small, and it would appear to be inversely proportional to the molecular weight of the hydrocarbon. The energy dissipated by the spark is somewhat ambiguous in the original article. Assuming that the previous experiments were similar to those using mixtures of hydrocarbon gases—that is, a 1 msec spark carried several amperes at 10^3 V—then only about 10 J may have been deposited in the gas mixture within the enclosed vessel.

Nauer observed that the luminous clouds were not affected by external electric and magnetic fields. The color of the luminous clouds was variable but directly dependent upon the admixture gas; all colors were possible. The luminous cloud did not appear as a burning phenomenon but rather as an electrical glow discharge—a soft glow apparently emanating from the surface of the glowing body. Mixtures of colors, uniform colors, streaks, and stripes were also observed. The light from hydrogen was pale blue and that from benzene or propane vapor was visible in a brightly lighted room.

The luminous clouds exhibited motion, generally rising, although both up and down motion was also observed. The speed of motion was measured as 0.33–10 m sec^{-1}. No noise was detected from the phenomena at low mixture levels. A slight rustling noise was detected at high mixture values. The cloud dissipated predominantly without noise but occasionally with a loud noise when the cloud contacted the lid of the container.

One specific trait stands out as being of some significance. The vessel was separated into compartments by a flat disk with a 7-mm central hole placed within the enclosure. The luminous cloud was normally extinguished when it contacted the disk. However, a number of times the luminous cloud appeared to pass through the hole and regain its previous size and shape.

Nauer concluded that there is a definite correlation between natural ball lightning and the laboratory-produced luminous clouds formed by a low-density hydrocarbon excitation mechanism. It was proposed that ball lightning has no electrical nature at all. An initial electrical discharge is required to ignite the low-density combustion process but further electrical activity is not necessary. Combustion produces the observed luminous clouds. It was also suggested that possibly no hydrocarbon need be present prior to the discharge. Rather, the discharge dissociates

water vapor, forming hydrogen, which is used in the combustion mechanism. Whether these speculations apply in nature is a matter of conjecture and has not been verified. We conclude that the experiments of Nauer with low-density hydrocarbon combustion were the most significant since those of Plante, some 70 years earlier.

Nauer's experiments were continued by Fehr (1963), who investigated other hydrocarbon gases and evaluated the motion and lifetime effects with the low-density combustion process. He repeatedly produced luminous clouds in a hyrdocarbon atmosphere. The phenomenon was also initiated by an electric spark in his studies.

The important results of Nauer and Fehr were largely unknown to most investigators of ball lightning. Nauer's work was published in German in journals not commonly reviewed for atmospheric and meteorological related experimentation. Fehr's work was published in Hebrew and again not readily available. Consequently, it was more than a decade until such experiments were widely known. The low-density combustion techniques were expanded by Barry (1967a,b; 1968a,c) and published in widely available journals, English, German, and Russian. Barry (1967a,b; 1968a,b; 1969) related a detailed description of the experimental apparatus used for the research of the low-density hydrocarbon combustion phenomena and provided insight into the low-density combustion process.

The concept that ball lightning phenomena may be related to a combustion process with hydrocarbon gases has been discussed by several investigators. Hildebrandsson (1885) was the first to publish such speculations, and Piltschikoff, according to Anon (1900b), was the first to conduct experimental studies involving hydrocarbon vapors. However, it was Nauer (1953, 1956) who first introduced a hydrocarbon gas into an enclosed atmosphere for controlled experimental evaluations. Barry (1967a,b; 1968a,c) was the first to produce a ball-lightning-like phenomenon at atmospheric pressure.

The experiments by Barry (1967a,b; 1968a,c) were specifically designed to investigate the production of a ball-lightning-like phenomenon with the assumption that one type of luminous phenomenon could be generated by the combustion of low-density hydrocarbon gases. A large laboratory volume was enclosed at standard atmospheric pressure and temperature, a specific amount of hydrocarbon gas was introduced, and a direct current discharge was triggered across a spark gap within the enclosed volume.

The experimental enclosure consisted of a six-sided, transparent plexiglas chamber with interior dimensions of 50.2 × 50.2 × 100.4 cm and a wall thickness of 0.62 cm. The high-voltage cables and tubing

used to introduce the hydrocarbon gas were passed through one wall of the chamber through sealable holes. The hydrocarbon gas was introduced by a standard liquid displacement method and completely mixed with the enclosed atmosphere by use of a small brushless nonsparking fan mounted within the chamber. After each experiment, the enclosure was emptied to eliminate the possibility of contamination of the succeeding trial.

The high-voltage discharge was obtained from a capacitor bank rated at 5 μf and 25 kV. The capacitors were charged using a laboratory-built, high-voltage power supply rated at 10 kV. The capacitors were oil-immersion type and rated for instantaneous discharge. The discharge circuit is shown in Figure 7.9. The discharge spark was mechanically triggered, and the discharge time was a few milliseconds.

The spark gap was formed by two copper electrodes placed 25 cm above the base of the chamber and along its central vertical axis. Various electrode dimensions, shapes, and separation distances were tested. It was found that the general configuration illustrated in Figure 7.10, with a gap of 0.5 cm, gave the most satisfactory results. This finding is similar to that found by Nauer (1959).

The process began by introducing 5.0 vol % of propane, mixing the atmosphere, and then triggering the discharge. The process was repeated, each time reducing the amount of gas introduced by 0.2%. As expected, normal combustion phenomena were observed at the beginning of the series of trials. As the hydrocarbon volume percentage decreased to less than that necessary for ordinary combustion (about 2.8%), no phenomena were observed. But in the range 1.4%–1.8% of gas, a small yellow-green ball of fire formed. It was brightly luminous,

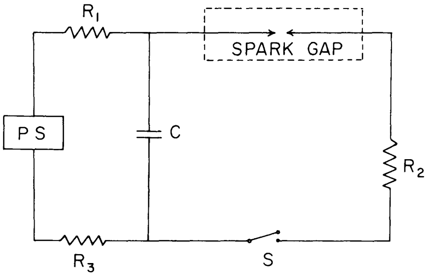

Figure 7.9. Schematic of the electrical circuit used by Barry (1967) to produce a long-lived illuminated ball-lightning-like phenomenon at atmospheric pressure in a low-density hydrocarbon gas environment. The capacitors were oil emersion type rated at 5 mf, 25 kV and were charged with a 10-kV power supply. The discharge was mechanically triggered, occurred in about 1 msec, and dissipated about 250 J.

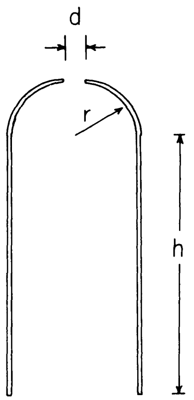

Figure 7.10. Drawing of the metal electrode geometry used by Barry (1967a,b) to produce a long-lived illuminated ball-lightning-like phenomenon at atmospheric pressure in a low-density hydrocarbon gas environment. The curved electrodes had a radius of curvature of $r = 1$ cm, a electrode separation of $d = 0.5$ cm and stood a distance of $h = 10$ cm above the base of the enclosure.

had a diameter of several centimeters, exhibited rapid random motion about the chamber, and decayed silently. A photograph of the phenomenon is shown in Figure 7.11. The ball of fire, interpreted here as a laboratory ball lightning, occurred at atmospheric pressure and had a lifetime of about 1–2 sec. Most importantly, the lifetime of the phenomenon extended long after energy ceased to be injected into it.

The energy available to the phenomenon from the discharge was about 2.5×10^2 J, neglecting the small impedance dissipations in the discharge circuit. The energy density of the ball-lightning-like phenomenon, would be about 7×10^{-3} J cm^{-3} assuming a 4-cm diameter and the ratio of the energy dissipated to the available energy as found by Powell and Finkelstein (1969, 1970) of about 1×10^{-3}. See Section 7.5 for more information. Refer to the discussions of ball lightning energy density, Chapter 4, Section 4.2.

It has been known for some time that an electric discharge within a simple hydrocarbon atmosphere will cause more complex hydrocarbons to be formed. Ponnamperuma and Woeller (1964) experimentally investigated such activity in attempts to understand the chemistry of the primitive earth and Jovian atmospheres. A methane atmosphere was enclosed in a test chamber and glow discharges and spark discharges were introduced, producing complex hydrocarbons. These included benzene, toluene, 2,2-dimethylbutane, 2-methylpentane, 3-methylpentane, 2,4-dimethylhexane, and 3,4-dimethylhexane; the most common molecule produced in pulsed discharges was C_6H_6.

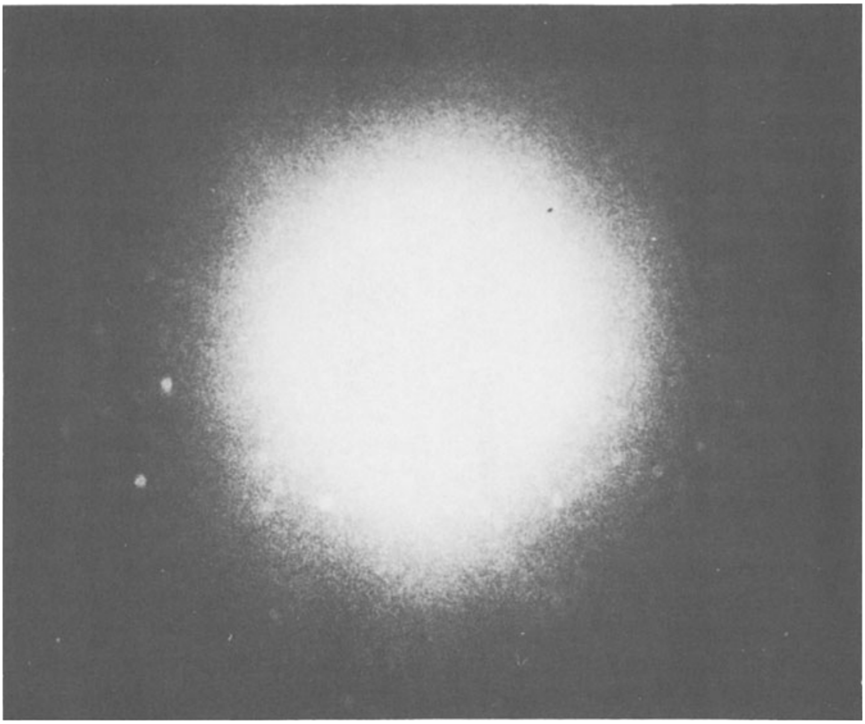

Figure 7.11. Still camera photograph by Barry (1966) showing the long-lived illuminated ball-lightning-like phenomena produced by the spark-initiated localized combustion of low-density hydrocarbon gas at atmospheric pressure.

Cawood and Patterson (1931a,b) demonstrated that volatilized aerosols when electrified form long polymer chains and clump together to form a single ball of material. They introduced hydrocarbon aerosols into an enclosed glass chamber of about 4 m^3 and charged the particles with a brush discharge. The charged particles formed into a sphere with a diameter of about 20 cm suspended at the center of the chamber. The charge of the sphere was apparently opposite to that of the discharge electrode. The sphere was of different color from the original substance and was composed of extremely long chains of individual members. A number of different hydrocarbons were used, one being *p*-xylene-azo-β-naphthol, which was introduced at a concentration of 15 mg m^{-3}. Its original color was green-blue in a Tyndall beam, but after electrification and clumping it became bright red in appearance. The linking of the curious electrification phenomenon to ball lightning was

made by Cawood and Patterson (1931a,b), Anon (1931), and Barry (1968a,c).

It has been speculated that the evolution of more complex hydrocarbons from a simpler one might aid the formation of a ball lightning. Barry (1968a,c) proposed that a low-density hydrocarbon flame could be responsible for one type of ball lightning phenomenon. The fuel for the flame would be low-density hydrocarbon vapors in the atmosphere, perhaps liberated by a cloud-to-ground stroke. The normally low density would be concentrated by the electrification clumping process investigated by Cawood and Patterson (1931a,b).

Low-density combustion phenomena have been experimentally investigated, for example, by Lewis and von Elbe (1961). Burning can exist as a spherical flame which can expand radially or remain stationary if fuel is caused to flow toward the center of the spherical flame from the surrounding region. It was suggested that a spherical-flame ball lightning could be ignited by an atmospheric discharge and feed upon the hydrocarbon concentrations. It would either exist at the central point of the hydrocarbon aerosol concentration, being fed by the continuing inward flow of particles, or move from one localized concentration to another.

Dimensional boundaries for a localized burning flame were derived from the spherical flame relation of Lewis and von Elbe (1961) as

$$E = \frac{d^3(T_b - T_a)Cp\pi}{6} \tag{7.1}$$

where E is the energy, d is the diameter, C is the specific heat of the hydrocarbon mixture, p is the mixture density, T_a is the initial temperature of the mixture, and T_b is the final temperature. If one assumes an initial CH_4 density less than that required for combustion, and a final more complex hydrocarbon density just great enough to support combustion within a small volume, for example, C_3H_8 at 3%, an available energy of 10^2–10^6 J, a specific heat of 0.28 cal g^{-1} °C^{-1}, a density of 0.2×10^{-3} g cm^{-3}, a final temperature of 4000°C, assuming color and temperature are related, then a spherical flame diameter of 6–130 cm is calculated.

Singer (1971) and Mills (1980) commented at length on the relationship between low-density hydrocarbon-burning phenomena and the natural ball lightning event. It was noted that the temperature of methane and propane burning in air at optimum conditions is 2000°C rather than 4000°C. At less than optimum conditions—that is, lesser partial pressures of the hydrocarbon—a lower temperature might be

expected. However, Singer recognized that, at low hydrocarbon concentrations, there may exist a different and less understood burning mechanism in comparison to normal flame combustion.

Some complex hydrocarbon molecules undergo cool oxidation in air when heated: pentane, for example emits a blue glow. The temperature of the reaction proceeds near 220°C and the color is attributed to emission from the formaldehyde molecule. Formaldehyde is thermochemically produced in an excited state by the cool oxidation reaction. The cool oxidation reaction, however, has not been verified to occur with methane or propane, although the experiments by Nauer suggest such a reaction.

The formation of complex molecules with methane and propane was verified during laser experiments by Barry, Boney, and Brandelik (1971). A mixture of helium, air, and methane or propane was exposed at low pressure (10 Torr) to a glow discharge. CO and CO_2 molecules were produced by the electrochemical oxidation of the hydrocarbon gases. The CO and CO_2 molecules were also vibrationally excited and could store energy for a subsequent laser process. In addition, molecules of NH_3NO_2, an explosive compound, were formed during the methane oxidation reaction. Several explosions occurred during the experiments.

We may speculate that the reaction producing NH_3NO_2 molecules at low pressure may also operate at atmospheric pressure under some optimum conditions. The reaction could proceed to a degree where sufficient NH_3NO_2 molecules were produced to cause an explosion, thereby terminating the reaction in a noisy manner.

It must be recognized that the ball lightning formation mechanism involving low-density hydrocarbon combustion cannot account for all instances of ball lightning appearance. The naturally occurring volume abundance of CH_4 in the atmosphere is only about$10^{-4}\%$ as indicated by Ratcliffe (1960). If the atmosphere were the only source for a 1% volume concentration of CH_4 in about 10^5 cm^3 (the laboratory volume), it would be necessary for any clumping process to operate effectively over a spherical volume with a radius of about 100 m. If the natural abundance of CH_4 were greater value than $10^{-4}\%$ within a smaller region, then the clumping process would not need to be so radially extensive. This implies that the process would be more probable near those localized atmospheric regions of increased hydrocarbon content, for instance, above a marsh or natural gas seepage area.

Baker-Blocker, Doanhue, and Mancy (1977), for example, have shown that the methane flux above wetland areas (marshes and swamps) may increase significantly with increased temperature. One may speculate that ground lightning strokes could liberate relatively substantial

amounts of methane in a very localized area. Such a process could provide the hydrocarbon density necessary to support the combustion process. Hubert (1975a), as a result of experiments with triggered lightning, made photographs of persistent, luminous globes formed near the earth after cloud to ground discharges. He speculated that localized concentrations of combustible gases could be evolved from the ground or surrounding material at the point of the lightning stroke. Refer to Figures 7.2 and 7.3, which illustrates a persistent illumination which appeared at ground level as a result of a triggered cloud-to-ground lightning discharge.

The formation of spherical flame phenomena in the atmosphere was also investigated by Kekez and Savic (1977). Their experiments were based on the electrolysis of water by a 120 V-high current pulse to form a hydrogen-oxygen bubble which was then ignited by a pulse from a 80 kV Marx generator. The resulting flame had a bluish color and lasted for about 0.5 sec. The flame apparently lasts as long as the supply of the proper hydrogen-oxygen mixture can be maintained by the diffusion processes in the surrounding region. The limited experiments of Kekez and Savic (1977) were conducted at a pressure of 70–150 Torr; extensive experimentation was not completed. Further experimentation at atmospheric pressure is needed to properly evaluate the concept. It has been proposed that the spherical flame can be naturally formed in the atmosphere and supported by the formation or release of flammable gases, such as hydrogen and methane. Its life would be controlled by the diffusion of these gases into the region of burning.

Near-spherical combustion flames with CH_4–O_2, were studied by Powell and Domish (1969) in homogenous steady fields. Large plane parallel metal sheets were used as electrodes with gaps of about 20–60 cm (8–24 in.). Spherical flames were produced with diameters of 5–15 cm (2–6 in.). The results were supportive of the model of Powell and Finkelstein (1969). See Section 7.5.

Marcet (1888) discussed an observation of an energetic globe of fire at a peat bank, which is suggestive of the concept of combustible gas evolution with subsequent combustion. A red luminous ball with a diameter of 60 cm (24 in.) was initially observed as it slowly descended into a valley. It then appeared and disappeared as it repeatedly dipped into the peat, dislodged large quantities of the material, and left sizable holes. The complete event was reported to have lasted about 20 min.

The low-density hydrocarbon flame concept would not account, however, for ball lightning occurrences observed in regions that are not subject to hydrocarbon gas concentrations. It is for that reason, as well

as others, that we are compelled to view the hydrocarbon gas oxidation mechanism as possibly being responsible for one type, but not all, of the ball lightning appearances.

7.4. *Type 3: Metallic Vapor*

Ball lightning and other luminous phenomena, if assumed to be purely electrical or electrochemical in nature, may be investigated by techniques available in the laboratory. Such research, we have seen, has occurred with varying results. Investigation of a ball-lightning-like phenomenon caused by a vaporized solid is more difficult under controlled laboratory conditions because of the plasma nature of the product. Several instances, both controlled and accidental, have occurred that have allowed some study. The observations indicate that a metallic vapor, a plasmoid, can exist in air, apparently self-contained and independent of the formation mechanism. If viewed without knowledge of the method or origin, one would classify such phenomena as ball lightning. This again supports the hypothesis that numerous phenomena can occur, all of which may be and have been classified as ball lightning.

Neesen (1900) was apparently the first to speculate that the ball lightning phenomenon could be composed of vaporized, thermally glowing, and fragmented metal material. The composition of such phenomena must, however, be recognized as a matter of speculation as Lodge (1905) noted, since laboratory study and research had not at that time supported the concept. Norwegian hydroelectric engineer A. Nielson, as reported by Brand (1923, 1971), demonstrated that luminous phenomena could be produced by the shorting of contacts on a high-power direct current generator. The generator was shorted by placing a water resistance electrically in parallel with the shorting device.

A reddish luminous mass with a diameter of 5 cm was observed to float from the shorted area and remained visible in the air for a few seconds. Photographs of the event were made and are reproduced here as Figure 5.22 and Figure 5.23. The event was repeatable and could apparently be produced at will. Figure 5.22 shows a large luminous air mass, apparently formed at the time of generator shorting. An individual entity, a luminous ball, apparently separated from the larger luminous mass. Figure 5.23, taken a few moments later, shows the ball having risen above the large glowing mass.

A large amount of energy was dissipated during the shorting of

the contacts. The generator developed 10^7 W at 12 kV so that if the discharge took 1 msec, over 10^4 J would have been available for the ball formation.

Another short-circuit phenomenon was reported by A. T. Jones (1910). A length of copper wire was accidently placed across the terminals of a standard 110-V circuit. An incandescent ball appeared at the instant of the short circuit and slowly rolled across a table and disappeared. The ball appeared to be about 3 cm in diameter and its color was yellow-white. The top of the table was inspected and a line of scorched points on the surface was found, as if the ball had bounced along the wood. The scorched spots were a few centimeters apart. The scorched line ended at a crack in the top of the table. Immediately below the crack was a drawer. A small copper ball with a diameter of about 1 millimeter was found inside.

It was speculated that the copper ball was the residue of the observed luminous ball and that the incandescent object had been composed of copper vapor. It was noted that the green color, usually characteristic of copper vapor, was not observed. This may be a thermal emission limitation due to the energy deposited at the time of the ball formation. An experiment repeating the accident was apparently never performed. A number of questions remain.

Smirnov (1977) briefly discussed the types of ball lightning, one of which was thought to form when lightning strikes a solid medium, perhaps a metal. It was suggested that a glowing ball could consist of a metallic gas at a temperature of about 2000°C. The ball so formed would be heavier than air and might exist in contact with the ground for some period. The unpublished reports on this topic were not available to this author.

A similar observation has been reported and discussed by Silberg (1962, 1965). A fireball phenomenon was accidently produced during the shorting of the contacts of a circuit breaker on a submarine. The phenomenon is well documented and was repeatedly produced under quasicontrolled conditions.

The submarine had two sets of batteries and two generators for charging. The generators were normally connected through a reverse-current relay so that either generator could be used with either battery set. The main contacts of the circuit breaker were made of silver with copper extensions and a blowout coil. The faces of the silver plates made physical contact with one another. The reverse-current relay was used to disconnect a charged battery from a nonoperating generator should accidental connection be made.

Accidental connection was occasionally made, and the reverse-current relay would automatically separate the closed contacts. At that time, an arc was formed across the silver contacts, and the blowout coil forced the arc onto the copper extensions to minimize erosion of the contacts. Normally, the arc was rapidly extinguished. However, sometimes the battery charge would be sufficient to maintain an arc across the copper extensions. A green-colored, incandescent fireball was then observed to float off the contacts into the surrounding area. The floating ball would last for about a second. Silberg speculated that the green color was due to neutral copper vapor radiation from the plasmoid.

Tests were conducted at the Philadelphia Naval Shipyard in 1974 on the reverse-current gear of the USS Cutlass. A fireball was produced in the engine room at a direct current of 156,000 A and 260 V, a peak power of 4×10^7 W. Switching times were from 10 to 100 μsec so that an energy of 0.4 to 4×10^6 J was dissipated in the experiment. The ball diameter was observed to vary from about 10 to 15 cm. Refer to the discussions on ball lightning energy density, Section 4.2, Case 7.

That ball lightning might result from a metal rapidly heated to produce an atomic metal vapor cloud was also suggested by Potts (1910), based upon an earlier observation. During a heavy electrical storm, several balls of fire were observed rolling along a street. One was 60–90 cm in diameter and the others were smaller. This occurred immediately following a heavy lightning discharge to a telephone pole some distance away. The induced current and heating in the telephone wire caused a section to melt off. The broken segment was sent spinning along the street giving the appearance of an illuminated moving ball. The smaller balls could have been due to smaller wire lengths heated and sent spinning or to vaporized clouds of wire.

The continued existence of a luminous ball composed of vaporized metal or hot gases which exhibits the characteristic of bouncing along the ground would require a certain degree of insulation from conductive and convective losses. Dr. C. Kennedy, among others, pointed out that this might be accomplished by rapid evolution of water vapor from the wet ground under the ball. The water vapor would provide a thermal barrier between the relatively hot ball and the wet surface. This is analogous to the protective water vapor film produced by a water drop on a hot griddle. The drop is sustained far longer than would be expected by the insulating properties of the water vapor barrier between the drop and the hot surface.

It would seem that conclusive evidence exists by these documented and repeatable observations that a glowing phenomenon can be pro-

duced by high-current discharges. It must be mentioned, however, that we have no specific scientific verification that the phenomena were caused by metallic plasmoids. This is not to suggest that the phenomena were not real and present, but rather that the existence of a stable metal vapor plasmalike object is a matter of speculation at this time. The high-current discharge phenomena may well represent another form of the ball lightning phenomenon.

An investigation related in concept to the metallic vapor experiments was conducted by Andrianov and Sinitsyn (1977). They caused a discharge to occur within an evacuated chamber with walls of dielectric materials. The chamber was separated from the lab atmosphere by a thin membrane which ruptured during the discharge condition. The discharge caused erosion of the dielectric material which formed a luminous erosion plasma. The erosion plasma was ejected into the lab atmosphere as the cell ruptured. The plasma remained visible for about 10 msec.

It was speculated that the experiments could be analogous to a lightning strike to the ground, heating and ejecting material to form a luminous ball. The concept is essentially the same as that suggested by Trecul (1881) and Fieux, Gary, and Hubert (1975). Refer to Section 7.2.

Andrianov and Sinitsyn (1977a,b) used a capacitor bank with C = 80 μf, an initial voltage of 12 kV, and an energy of about 5000 J, and they achieved a discharge current peak value of about 12 kA. The discharge occurred with the chamber evacuated to about 10^{-5} atm initially, and they used several different dielectric materials on the wall. The material ejected by the discharge into the chamber was estimated as having been about 3×10^{-2} g. A glowing plasma was produced which lasted longer than expected of a plasma in the atmosphere. A fully ionized plasma would be expected to decay in about 10 μsec at atmospheric pressure according to Kapitza (1955, 1961).

The results of the experiment were illustrated in a series of time-sequence photographs. The erosion plasma initially appeared to be ball shaped and gradually became vortex shaped. The phenomenon lasted only a few milliseconds and was quite luminous. Andrianov and Sinitsyn recognized that the intensity of the erosion plasma was far greater and the life far shorter than that of natural ball lightning. Direct analogy to ball lightning formation was not made. Rather, it was noted that a glowing, relatively long-lived, erosion plasma could exist at atmospheric pressure. The creation of the vortex structure may have been important in its long life and related to its formation mechanism and perhaps to that of one type of ball lightning.

7.5. Type 4: Electrodeless Discharges

Improvements in electrical and electronic technology during the late 1800s initiated more sophisticated means of concentrating energy into a small volume of air. High-voltage discharges were replaced by radiofrequency discharges which have been quite effective in producing high-intensity, relatively high-temperature plasmoids within a localized region of air. Such techniques—for example, that by Hatch (1958) illustrated in Figure 5.39—have become popular in recent years in the investigation of fusion reactions.

Electrodeless discharges have been known since the late 1800s as Thompson (1891) and Tesla (1904, 1978) performed investigations of such phenomena. The results of the Tesla experiments, which have recently been directly related to ball lightning research, have not been widely known. This has been due principally to the unavailability of Tesla's working diary of the 1899 experiments in Colorado Springs, Colorado. Tesla (1904) made only passing reference to his experiments with fireballs during a discussion of natural lightning events. He reported that he had produced artificial fireballs but did not elaborate on the experimental details. More recently, the experimental results of Tesla have been reported and discussed in the popular literature by Bass and Golka (1976), Blake (1977), Golka and Bass (1977), O'Neill (1971), Shunaman (1976), and Snigier (1976). Tesla's 1899 diary of the Colorado Springs experiments provides further (though incomplete) details and has recently been published and is available to investigators (Tesla, 1978).

It is known that Tesla conducted experiments with a set of three large coils: a primary, a secondary, and an extra coil, which was an extension of the secondary. The secondary and primary coils were about 15.5 m (51 ft) in diameter and 2.4 m (8 ft) high. The extra coil was mounted about 3.7 m (12 ft) above the floor and was 2.4 m in diameter and 2.4 m high. A discharge sphere (a spherical capacitor) of about 29 cm (1 ft) in diameter was mounted to the top of the extra coil.

The primary coil was connected to a capacitor bank of order 1 μf, driven by a 50-kW generator and coupled to the other coils (and each coil to one another) by induction. The primary coil developed about 12 kV, the secondary coil about 1×10^6 V, and the extra coil developed about 12.5×10^6 V. Tesla's breakwheel operated at a rate of 4.2 kHz and each discharge from the extra coil produced a pulse energy of about 12 J.

It was reported by Blake (1977), Golka and Bass (1977), and Snigier

(1976) that Tesla produced artificial ball lightning with a diameter of about 1.9–6-cm (0.75–2.5-in.).

Tesla hypothesized that the creation of ball lightning involved two phases. Initially, a small region of air is caused by a powerful lightning discharge to suddenly increase in temperature and experience an associated decrease in local gas pressure. The electrical resistivity of the region should increase according to Paschen's pressure-gap distance law. The initial discharge is then rapidly followed by a second discharge through the same channel. The second discharge—the second phase—further increases the temperature of the small region by Joule heating so that a pressure balance develops between the kinetic gas pressure and the atmospheric pressure of the surrounding cool medium. The hot gas (sphere) is then reported as a ball lightning if observed.

The concept of Tesla was formularized by Bass and Golka (1976) by equating the kinetic energy (pressure × volume) to the internal energy E of the fireball. The energy relation was given as

$$E = \frac{P_0 V}{\gamma - 1} \tag{7.2}$$

where P_0 is the pressure, V is the volume, and γ is the ratio of specific heat, $\gamma = 7/5$ for air. The original calculations assumed that the ratio of the ball energy E to that available E_0 was $n \cong 0.5$, and set P_0 = atmosphere pressure, a radius of 1.8 cm (0.7 in.) was calculated, agreeing well with the report by Tesla (1978).

The concept may be expanded to include a parameter ϵ which is the ratio of the ball pressure P to the atmospheric pressure P_0. An energy input efficiency ratio n/ϵ for the fireball is then given by

$$\frac{n}{\epsilon} = \frac{4\pi P_0 R^3}{3(\gamma - 1)E_0} \tag{7.3}$$

so that for a diameter of $2R = 3.8$ cm (1.5 in.)

$$\frac{n}{\epsilon} = 0.6 \tag{7.4}$$

The interpretation of the n/ϵ ratio may be made by considering that gas discharges, and possibly lightning channels as well, should have $\epsilon P \simeq$ 10 Torr (1 Torr = 1/760 atm) so that $\epsilon \simeq 0.01$, and $n = 0.006$. The value of n agrees well with that used by Silberg (1962, 1965) and is only slightly greater than the value measured by Powell and Finkelstein (1969, 1970).

The internal energy is then about $E = 0.07$ J and the uniform

energy density for a 3.8 cm (1.5 in.) diameter fireball, following equation (4.2), would be

$$\mathscr{E}_{BL} \simeq 2 \times 10^{-3}\ \mathrm{J\ cm^{-3}} \tag{7.5}$$

It is instructive to note that this value is comparable to the value deduced by Powell and Finkelstein (1969, 1970) from their experimental results and equivalent to that for a partially ionized air plasma of $N \simeq 10^{14}\ \mathrm{cm^{-3}}$.

In contrast to these seemingly favorable results, Martin (1894) discussed Tesla's earlier experimental work as having formed an artificial fireball but identified the fireball as a St. Elmo's Fire. There is some concern that the 1899 observations of Tesla might refer to a brushless discharge phenomenon since the existence of the fireballs in Tesla's discussions were not specifically defined as continuing after the termination of input energy to the coils. However, Tesla commented that the fireball existed for a measurable period of time and made photographs of the phenomenon. The photographs have not been available to this author for evaluation. In lieu of the Tesla (1978) diary and the general discussions in the popular literature. we must assume that the observed fireballs were some form of ball lightning.

In addition, Tesla (1904, 1956) reported that he had also repeatedly detected standing electromagnetic waves in the atmosphere during thunderstorm conditions. It has since developed that several ball lightning theories, for example, those by Marchant (1930), Cerrille (1943), and Kapitza (1955, 1961), have been independently advanced suggesting that such standing wave activity is necessary and required for the continued existence of ball lightning. Although Tesla's experimental work has gone largely unknown, it may yet become widely recognized as having been important in the experimental production of ball-lightning-like phenomena.

In a different location, at a later time, and under less favorable conditions, other experiments with radiofrequency electrodeless discharges were conducted by Babat (1942, 1947). It would appear that Babat was the first to perform extensive, detailed, and widely published investigations of radiofrequency electrodeless discharges with high-power oscillators. It was the formation of such discharges at atmospheric pressure that singled out Babat's work for evaluation by many ball lightning investigators. Babat's results were specifically related to ball lightning by Leonov (1966) but only by inference by Babat (1942, 1947), with his term for the discharge phenomenon being a "fire-ball."

Electrodeless discharges are essentially the formation of a discharge in some medium at a distance away from a radiofrequency electrode or

antenna. The radiated electromagnetic fields are concentrated at the focus of the antenna, and the intense electric and magnetic fields can effectively cause ionization of the medium, creating a plasmoid which appears to be suspended without attachment to any object.

Babat investigated electrodeless discharges in high-frequency electromagnetic fields at frequencies from 10^6 to 10^8 Hz. The electric field strength in the discharge space was varied from tens to hundreds of volts per cm. The power introduced into the discharge space was from fractions of watts to 100 kW.

An electron tube ultra-high-frequency oscillator was used to produce discharge frequencies up to 10^8 Hz and discharge power to 100 kW. The high voltage was supplied by a direct current source with a capability of 10 kV and supplied through a choke coil (L_1) which was connected to the central point of the conductor between the tube plates. A schematic of the circuit is shown in Figure 7.12. The choke coil was made from 10 turns of square (10 × 10 mm), rectangular (10 × 20 mm), or circular (13 mm diameter) copper tubing to form a coil of 100 mm diameter and 100 mm long. A similar choke coil was connected from the center point of the conductor between the grids to a 400-Ω grid-leak resistance (R) to ground.

The filaments in the ultra-high-frequency oscillator were grounded through a reactance in order to maintain proportionality between the phases and amplitudes of the grid and plate voltages. The frequency of the oscillator was controlled by varying the dimensions and the form of the grid and plate conductors.

The electrodeless discharges produced by Babat (1947) were normally ignited at some low pressure within an enclosed bulb. The pressure was then varied to investigate the glowing phenomenon.

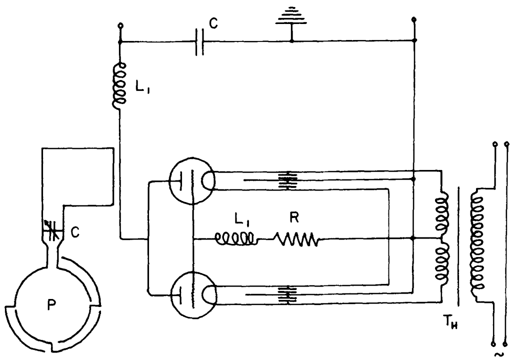

Figure 7.12. Schematic of the electrical circuit used by Babat (1947) to produce the original radiofrequency electrodeless discharges at reduced pressure. The radiofrequency energy was balanced by tuning of the oscillator circuit.

Discharges could also be initiated at atmospheric pressure if some means of achieving the initial breakdown were used.

The discharges had appearances that varied with pressure and power. The discharges at 10^6–10^7 Hz and at pressures from about 0.1 mm to about 10 mm Hg pressure resembled a hollow cylinder pressed to the walls of the discharge tube. At higher pressures, the discharge was yellow-white and moved about the vessel frequently touching the walls. At pressures of tens of mm Hg a fiery sphere was formed. At even higher pressures, the sphere expanded, and fiery fingers spread from its poles. At atmospheric pressure, the discharge was spindle shaped with a bright middle and a faintly shining outer layer and it moved somewhat about the tube.

Somewhat similar colors and shapes were observed as the frequency was varied. Even concentric zones and different colors within a single discharge were observed. Colors varied from red to brown to green to yellow and shapes varied from fiery balls to luminous spheres to elongated rods. However, all of these discharges were dependent upon the input of the radiofrequency energy for their existence. The discharges extinguished immediately if the radiofrequency power was terminated. Only at pressures below 2–3 mm Hg was a luminosity observed after the electrodeless discharge ceased. After a relatively intense discharge was extinguished, a green milky mist filled the discharge bulb and lasted for several seconds.

The work by Babat was not originally related to ball lightning. Babat was concerned with possible industrial applications of radiofrequency power. He mentioned such items as gas electrochemistry, oxidation of nitrogen, acetylene production, deformation of fireproof materials, and the design of high-intensity light sources. The apparent similarity between the appearance of electrodeless discharges and ball lightning was recognized by numerous scientists soon after Babat's reports. The use of electrodeless discharges in the experimental study of ball lightning was continued and investigated by other scientists.

Almost two decades after the experiments by Babat, Harrison (1958) began investigations of laboratory-produced electrodeless discharges and reported ball-of-fire phenomena at 10^{-4} mm Hg pressure. The electron temperature was high, of order 1×10^5 °C, and the electron density was small, of order 10^8 cm^{-3}. Wood (1930a,b) was apparently the first to term the luminous ball- and spindle-shaped objects observed at low pressure with electrodeless discharges as plasmoids.

C. W. Hamilton (1960) and Ritchie (1963) performed experiments to corroborate Babat's work and to investigate the nature of the

ionization produced. A pulsed *X*-band radar (about 9×10^9 Hz) was used as the microwave transmitter source. A peak power of about 21×10^3 W was obtained by Ritchie with 0.5 μsec pulses and an interpulse period of 290 μsec. The pyramidal horn antenna of the radar unit was directed towards a parabolic reflector. The reflector concentrated the microwave energy into a 10-cm- (4-in.-) diameter evacuated glass bulb placed at its focus. The pressure inside the chamber varied from 0.1 to 77 mm Hg. The glass bulb was 60 cm (23.6 in.) from the antenna.

An electrodeless discharge was freely produced in the bulb in air at pressures ranging from 0.3 to 47 mm Hg. Color and size varied with the pressure. The discharge was extinguished at pressures above 47 mm Hg. Ritchie was not able to produce discharges at atmospheric pressure as had Babat (1947). Apparently, the formation is dependent upon a very powerful transmitter. Babat's transmitter had an output capability of 100×10^3 W, while Ritchie's had an average power of only 50 W.

Ritchie observed red sausage-shaped discharges near 1 mm Hg. At 5 mm Hg pressure, the discharge was irregularly shaped, striated, and brilliant opaque violet in color. Above 10 mm Hg, the discharge was bean shaped with a thin blue halo. Ritchie included a photograph of the discharge, which is reproduced here as Figure 5.40.

The temporal ionization characteristics were investigated by means of a photomultiplier tube. The discharge emissions were measured to build up in about 0.2 μsec and to fade with a relatively long time constant. The degree of ionization was assumed proportional to the light emission and therefore reached its peak in about one-half the microwave pulse period. The ionization decay time was also apparently longer than the interpulse period.

Ball lightning as an electrodeless discharge phenomenon has been the subject of serious debate by a number of scientists interested in plasma confinement and possible applications. It has been assumed that ball lightning is some type of plasma phenomenon and that by understanding the plasma physics involved one could apply the basic principles to other problems.

Ritchie (1959) speculated upon the potential use of ball lightning phenomena produced by electrodeless discharges as future weapons. Other researchers besides Babat, for instance, Cade (1962, 1964), Kapitza (1969), Konieczny (1963), and Maksimenko (1964), discussed the possibility of producing a plasma discharge at large distances from the focusing antenna. Ritchie (1961) edited a collection of Soviet scientific papers devoted to ball lightning, electrodeless discharge research, and plasma confinement theory. The papers apparently rep-

resented a cross section of Soviet thought on the problem in the early 1960s.

Soviet research on ball lightning was also reported in a series of papers in the journal *Foreign Science Bulletin.* Various radiofrequency discharge experiments have been performed and reported in that journal. One, by Balyberdin (1967), was performed to investigate the ball lightning event which was reported to have occurred on an aircraft by Wojskowy (1966). The nose cone of an aircraft in flight was simulated by a parabolic metal surface with an incident plasma flow. The region was also subjected to 30 GHz electromagnetic radiation yielding plasmoids in the surface gas layer. Specific characteristics were not reported.

Balyberdin (1975) later reported on experiments designed to reproduce ball lightning phenomena at the high field position of an *S*-shaped electrode. He worked at atmospheric pressure with a pulse voltage generator with a working potential of 150 kV and a dielectric impeded discharge gap. Discharges of about 2 kJ intensity with peak currents of 7×10^3 amp lasting about 70×10^{-6} sec could be produced. Balyberdin took streak camera records of the luminous clusters produced. It was found that the short-lived luminous plasma clusters were similar in structure to cylindrical vortices composed of low-temperature plasma. The phenomena did not possess the same complex properties attributed to ball lightning.

The use of radiofrequency discharges for ball lightning investigations was significantly advanced by the work of Manwaring and the subsequent experiments of Powell and Finkelstein (1969, 1970). Manwaring, as reported by Powell, Finkelstein, Zucher, and Manwaring (1966) and later by Finkelstein (1968), produced glowing ball-shaped, long-lived luminous phenomena in laboratory air at atmospheric pressure in 1965. He used a 7.5×10^7-Hz radiofrequency discharge arc between open electrodes. The glowing ball could be detached from the electrodes by increasing the electrode separation distance. More importantly, the ball would last about 0.5 sec after the radiofrequency excitation was terminated. The ball also rose above the electrodes, apparently due to thermally induced motion.

Work was continued at atomospheric pressure by Powell and Finkelstein (1969, 1970) with a 30×10^3-W radiofrequency power generator at 7.5×10^7 Hz. A luminous ball, actually a slightly cylindrical shaped object, was initially formed within a 15-cm internal diameter glass cylinder which included a short vertical section. The terminals of the radiofrequency oscillator were passed into the glass cylinder by electrical feedthroughs. The electrodes were movable and separable so that one electrode could be moved axially along the glass cylinder. A discharge arc was initially formed in the gap between the two electrodes.

The discharge continued and grew in size as one electrode was moved away from the other, forming a luminous column. A photograph of the experimental apparatus is shown in Figure 7.13.

The luminous column transformed into a quasi-ball-shaped glowing object, which rose to the top of the vertical glass tube after the radiofrequency excitation was terminated. The glowing ball would remain apparently unperturbed for 0.5–1 sec if convective mixing was limited by the confining cylinder. It would last about half as long in open air when unconfined. A photograph of a long-lived, radiofrequency-excited luminous phenomenon at atmospheric pressure is shown in Figure 7.14. The experimentally produced luminosity was found to be repeatable in the controlled environment of the laboratory and was investigated in some detail.

The voltage of the radiofrequency terminal used in the formation of the radiofrequency excited air mass was measured as 5000 V. The electron density was measured 0.1 sec after the radiofrequency input was terminated as 3×10^{12} electrons cm^{-3}. The ball lifetime could be

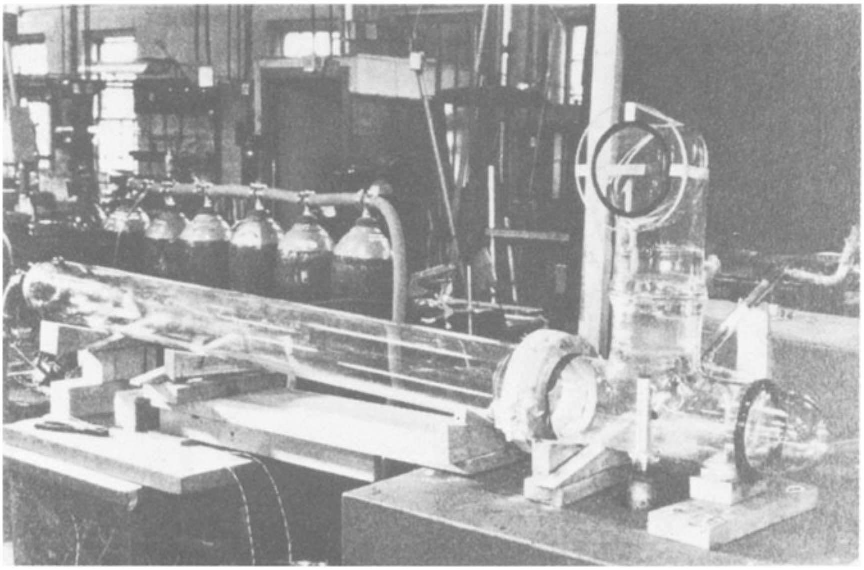

Figure 7.13. Still camera photograph of the experimental apparatus used to produce a long-lived luminous phenomenon at atmospheric pressure. The radiofrequency discharge was originally produced within the horizontal tube and drifted up the vertical section after termination of the input power. Reproduced with permission from J. R. Powell and D. Finkelstein, "Structure of Ball Lightning," *Advances in Geophysics,* Vol. 13, 1969, p. 141. A similar photograph was published by J. R. Powell and D. Finkelstein, "Ball Lightning," *American Scientist,* **58,** 1970, p. 262.

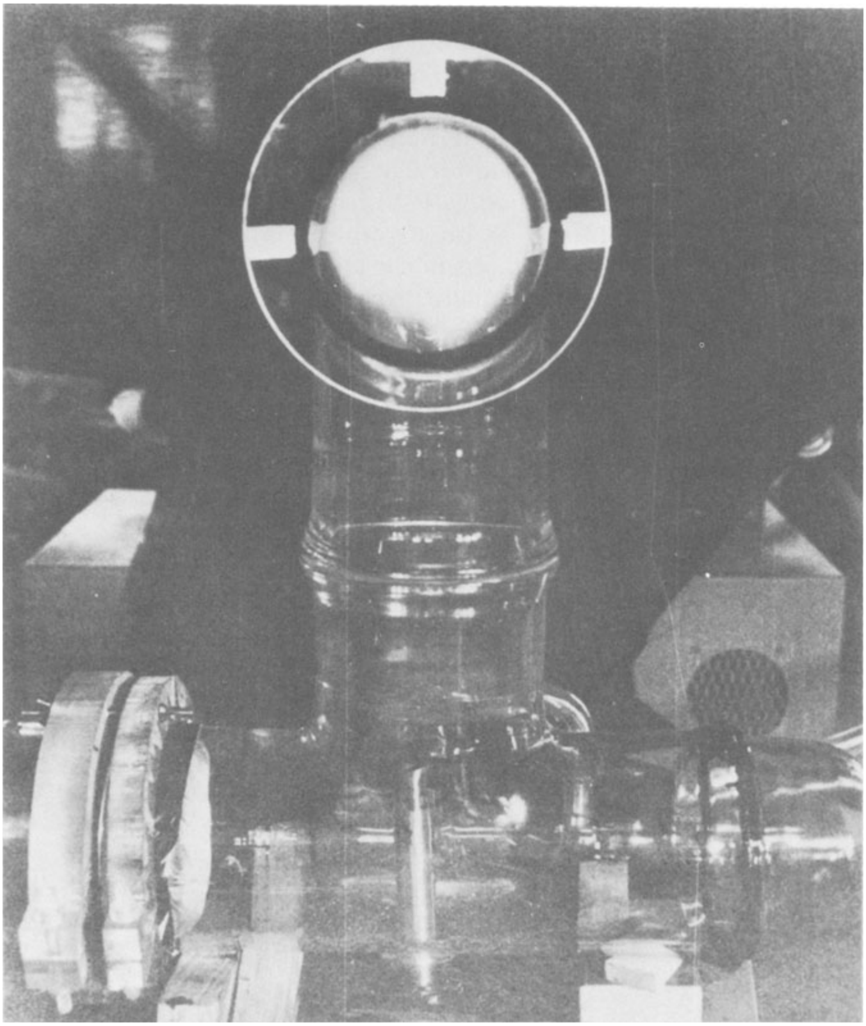

Figure 7.14. Still camera photograph of a long-lived luminous air mass created during a laboratory experiment at atmospheric pressure. The luminous air mass was created by focused radiofrequency electrodeless discharge. The phenomenon would be identified as a ball lightning if witnessed in nature. Reproduced with permission from J. R. Powell and D. Finkelstein, "Structure of Ball Lightning," *Advances in Geophysics,* **13,** 1969, p. 141. A similar photograph was published by J. R. Powell and D. Finkelstein, "Ball Lightning," *American Scientist,* **58,** 1970, p. 262.

increased by applied electric fields. The ball occasionally disappeared suddenly with a loud noise.

The decay of the ball emissions was exponential with a time constant of 0.2–0.3 sec. The total energy of the glowing ball in air was of order 4–15 J and the energy density of order 2×10^{-3}–9×10^{-3} J cm^{-3}. The associated metastable concentration was about 4×10^{15}–14×10^{15} molecules cm^{-3}, so that about 0.01% of the air molecules were excited. Both visible and near-infrared emissions were detected. The ratio of the measured energy of the glowing ball to that available for its formation is about 1×10^{-3}, in contrast to previously assumed values of 1–10%, for example, by Silberg (1962, 1965). This measured value is far superior to any assumed value and has been used in Chapter 4 to deduce information about the energy density of ball lightning and its natural form in the atmosphere.

The effects of gas pressure, gas composition, and electrode composition were studied relative to the characteristics and appearance of the glowing ball. The long-lived luminous balls could be obtained at pressures from 0.5 to 3 atm. Various gases, such as O_2, N_2, NO_2, CO_2, and argon were used. The long-lived balls could not be obtained in CO_2 or argon. Electrodes of Pt, Au, Ag, Cu, Zn, Cd, C, Sn, W, Al, and Pb and also Hg-coated electrodes were used. Long-lived luminous balls could not be obtained in Pb- and Hg-coated electrodes. It is probable that the complicated and multileveled atomic energy level structures of Pt and Hg atoms are such as to provide too many deactivation paths to allow an excited metastable molecular level to remain undisturbed long enough to provide energy storage.

The emission spectra and decay time of the glowing phenomena were influenced by the electrode material. The spectra from a N_2 luminous ball consisted solely of atomic line emission from impurities introduced from the electrodes. The identified line spectra of N_2 made with a 0.5–m Jerrell-Ash spectrometer are shown in Figure 7.15. No band structures were detected and no continuum recorded. This is in contrast to the emission spectra from a glowing long-lived ball in air with little electrode influence.

The spectra of the glowing air ball consisted mainly of band structures with few atomic line emissions. The most prominent bands in air were due to the Schumann-Runge of O_2 (3370–3617 Å), OH bands (3064 Å), PtO bands (5664 and 5906 Å), and CO_2 continuum (from 3500 to beyond 5100 Å). The CO_2 emissions were the most intense, as can be seen in the typical air spectra shown in Figure 7.16. Impurity line spectra were also detected but were of secondary importance in comparison to the CO_2 continuum.

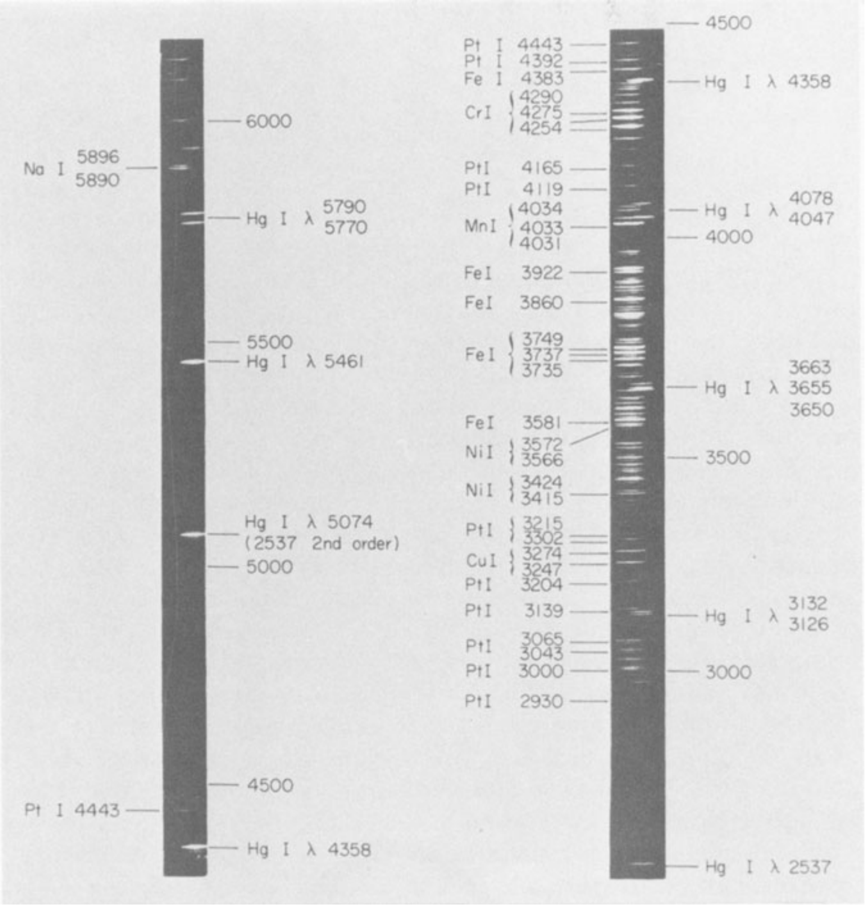

Figure 7.15. Typical spectrograph of the long-lived N_2 afterglow luminosity initiated by radiofrequency excitation. The spectrum was recorded by a 0.5-m Jarrell-Ash spectrometer with 20 Å per millimeter dispersion. The spectrum is solely due to line spectra from impurities and material in the electrodes. No band structure or continuum emissions were detected. Reprinted with permission of Academic Press, New York, and Dr. J. R. Powell. Originally published by J. R. Powell and D. Finkelstein, "Structure of Ball Lightning," *Advances in Geophysics,* **13,** 1969, p. 141, and reproduced by J. R. Powell and D. Finkelstein, "Ball Lightning," *American Scientist,* **58,** 1970, p. 262.

In general, the long-lived luminous balls formed in N_2 gas were bluish and of relatively low luminosity, while those in O_2 were white and very luminous. Those in normal air were yellow-white and of intermediate intensity. The initial discharge in air was always white with a gradual change towards yellow as the NO_2 concentration in the

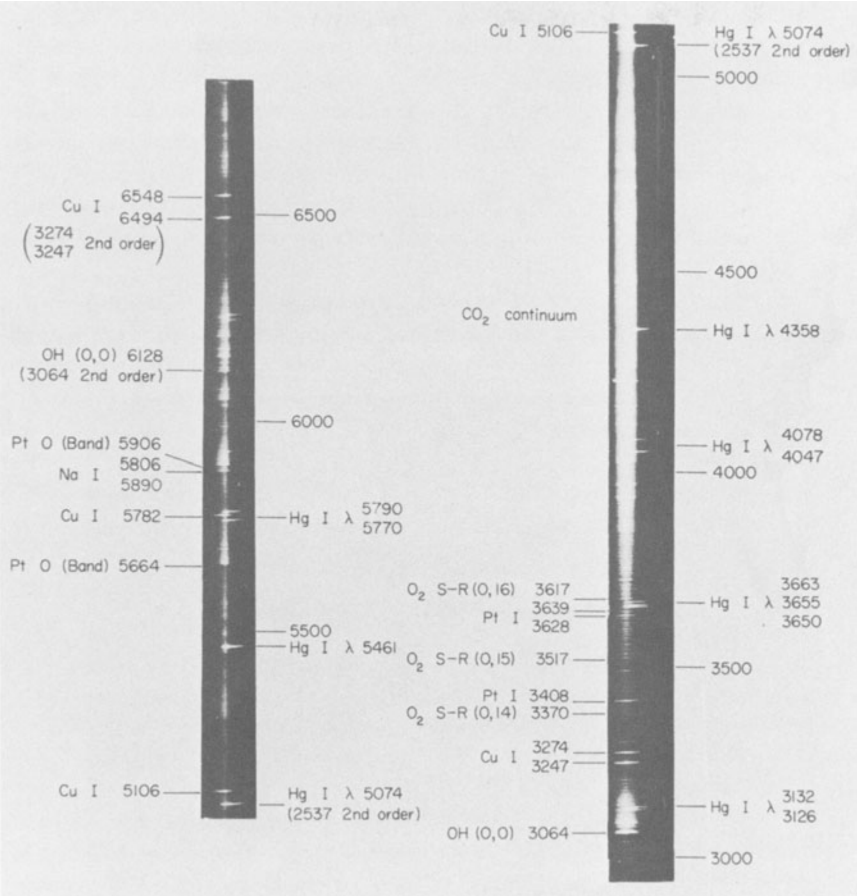

Figure 7.16. Typical spectrograph of the long-lived air afterglow luminosity initiated by radiofrequency excitation. The spectrum was recorded by a 0.5-m Jarrell-Ash spectrometer with a 20 Å dispersion. The air spectrum is significantly different from that with N_2. The line spectrum due to electrode material is secondary to the intense CO_2 continuum which dominates the emissions. Reprinted with permission of Academic Press and Dr. J. R. Powell. Originally published by J. R. Powell and D. Finkelstein, "Structure of Ball Lightning," *Advances in Geophysics,* **13,** 1969, p. 141, and reproduced by J. R. Powell, and D. Finkelstein, "Ball Lightning," *American Scientist,* **58,** 1970, p. 262.

discharge increased. In N_2O, the glowing balls were large, almost pure orange, and lasted as long as 2 sec after the radiofrequency discharge was terminated.

The emission characteristics of the radiofrequency-excited, long-lived, luminous phenomenon may be compared to those associated with

a natural lightning discharge. Orville (1966) investigated the time-resolved emission spectra of lightning strokes and published the results. One example is shown in Figure 7.17.

The atomic species responsible for the lightning stroke emissions are basically neutral and singly ionized oxygen and nitrogen atoms. Atomic emissions were not prominent characteristics of the radiofrequency-excited air mass. In general, such emissions were apparently lacking in the emissions from the radiofrequency-excited glowing air mass.

The studies by Orville (1966) also illustrated the time-dependent behavior of the lightning stroke emissions. The atomic nitrogen emis-

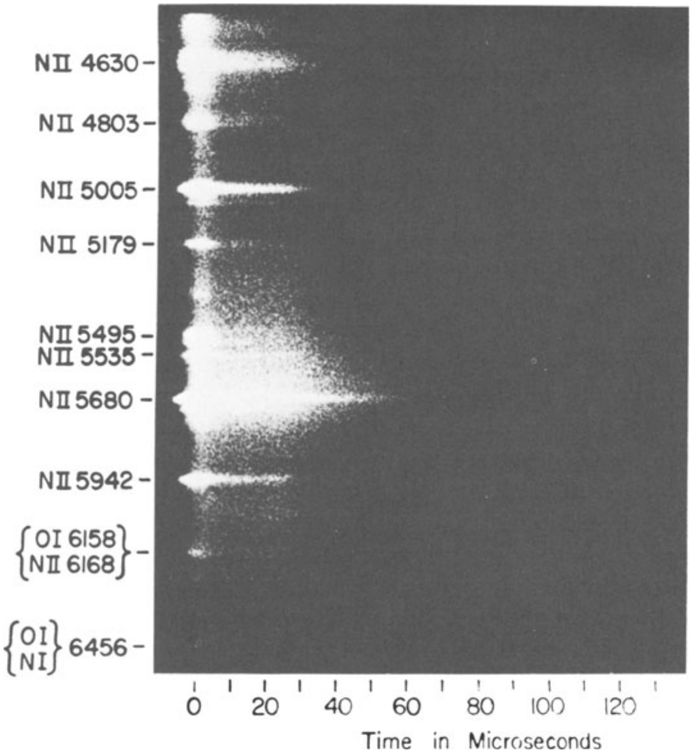

Figure 7.17. Emission spectrum of a normal lightning stroke which identifies the atomic species responsible for the luminosity. The time behavior was also recorded. The photograph demonstrates that the emission characteristics of a lightning stroke are not at all similar to those associated with the radiofrequency-excited, long-lived air mass. Reproduced with permission of R. E. Orville and *Science*, Washington, D.C., Copyright 1966 by the *American Association for the Advancement of Science*, from R. E. Orville, "High Speed, Time Resolved Spectra of a Lightning Stroke," *Science*, **157**, 1966, p. 451.

sions at 5680 Å were the most intense and lasted for almost 100 μsec. The time behavior of the lightning stroke is not at all similar to that of the radiofrequency-excited air mass. The radiofrequency-excited air mass lasted 0.5–1 sec, significantly longer than the normal lightning discharge luminosity.

The temperature measurements of the luminous phenomenon in air are not consistent with what would be required if the emissions were due to thermal processes. Temperatures of 2000 to 2500°K were measured with 75-μm-diameter tungsten wires by a resistance–temperature method. Also, the light intensity was mainly due to CO_2 even though the CO_2 concentration in air is only about 1%. Powell and Finkelstein introduced the term "electroluminescence" to describe a nonthermal radiative process, suggesting that the excitation of the CO_2 might have been by energy transfer from another molecule in an excited metastable state. The other molecule would then be responsible for energy storage within the plasmoid. It was speculated that $O_2^*(b^1\Sigma_g^+)$ may be excited by the discharge, then collisionally transfer energy to a ground state $CO_2(^1\Sigma_g)$ to produce $O_2(^3\Sigma_\mu^-)$ and long-lived $CO_2^*(^3B_2)$. The $CO_2^*(^3B_2)$ can decay to $CO_2^*(^3B_1)$, which in turn can radiate the observed CO_2 continuum.

Energy may be stored in air, in principle, by any molecule that has a long-lived metastable energy level that may be populated by a lightning-type discharge. A prime candidate, in addition to the $CO_2(^3B_2)$ suggested by Powell and Finkelstein (1969, 1970), is the $O_2(^1\Delta_g)$ molecule. The $O_2(^1\Delta_g)$ level is metastable with a spontaneous radiative half-life time under isolated conditions of about 45 min. Badger, Wright, and Whitlock (1965) experimentally studied the doubly forbidden $^1\Delta_g$–$^3\Sigma_g^-$ transition in O_2 and determined the pressure dependence of the radiative decay. The half-life decay could be reduced to a few minutes in air at standard temperature and pressure. The presence of vibrationally populated molecules as in a region of excited air could reduce the radiative half-life even more due to the availability of more paths of decay.

The (0–0) and (1–0) band transitions in the O_2 ($^1\Delta_g - {}^3\Sigma_g^-$) system occur at wavelengths of 1260 and 1065 nm. These transitions have been observed in normal atmospheric day and night glow emissions. Even though the $O_2(^1\Delta_g)$ level is metastable and the $^1\Delta_g - {}^3\Sigma_g^-$ transition is doubly forbidden, the population of the $^1\Delta_g$ level in air could be significant under certain conditions. It has been determined, for example by Pritt, Coombe, Pilipovich, Wagner, Benard, and Dymek (1977), that about 10% of the O_2 molecules can be excited to the $^1\Delta_g$ level by a microwave discharge.

We may expect, then, that a strong corona or a lightning discharge could significantly populate the metastable $O_2(^1\Delta_g)$ level in air. We also expect that the release of energy from the storage molecules could be significantly modified by contaminants in the air or by solid matter which may come in contact with the excited region.

These results of Powell and Finkelstein (1969, 1970), represent the most definitive experimental investigation of the ball lightning phenomenon. They conclusively proved that small volumes of air can be excited to produce long-lived luminous phenomena. These phenomena have the appearance of reported ball lightning phenomena, have a relatively low temperature, and possess energy concentrations similar to that assumed for ball lightning. The concentrations of N_2, O_2, CO_2, and NO_2 molecules in the air also directly affect the appearance of the phenomenon. Such molecular concentrations would also be influenced by the lightning discharge. The characteristics of color and luminosity may be dominated by the lightning-produced NO_2 concentration. The low energy density and temperature suggests a mass density essentially equal to that of normal air and a motion that could be influenced by electric or magnetic fields. Rapid cooling, such as by wind or by contact with some foreign matter, would lead to a rapidly terminated lifetime.

I consider these results to validate the basic assumption of the past few centuries, namely that air can be excited in some way to form a long-lived luminous phenomenon. We cannot extrapolate from the fact that a ball-lightning-like luminous phenomenon could be produced by radiofrequency discharge to suggest that the natural event could be or is formed by a similar mechanism. The experimental results should be examined, not the means of creating the result. A luminous, mobile, and long-lived, ball-like phenomenon has been produced by laboratory means and studied under controlled conditions. It does not matter what technique was used to create the energy concentration in air, only that such a phenomenon was finally produced.

7.6. Summary and Reflections

The various experiments have verified that small energized volumes of normal air as well as air doped with other molecules may be caused to remain luminous and stable for finite periods. It is important that we recognize that the manner by which energy is injected into the small air or quasiair volume, causing it to become luminous for a finite period, is unimportant. It is only necessary to realize that small air volumes or

quasiair volumes can be caused to remain luminous and stable and exhibit the general observational properties of the natural atmospheric events of ball and bead lightning.

We have discussed three general laboratory and/or controlled processes capable of concentrating energy into small regions of air at atmospheric pressure to produce long-lived, persistent, self-illuminated ball-shaped phenomena. These include (1) a localized burning process requiring combustible gases, (2) a localized heating process requiring vaporized materials, and (3) a localized excitation of air molecules to metastable states leading to energy storage. However, it is pure speculation to suggest that these phenomena may be naturally produced by a lightning discharge.

The concentration of electrical and thermal energy in a local region does occur in nature in phenomena more common than ball lightning. It is well accepted that the coronal discharge phenomena of St. Elmo's Fire, a low-current, high-voltage condition, occurs in nature. Air molecules and atoms are electrically excited and emit visible and near-infrared light during decay. Holtzer and Workman (1939) also showed that a rapidly moving leader stroke of a downward propagating channel can occur in a rather limited region which could locally deposit energy. The leader stroke tip has a certain electric potential and is therefore strongly influenced by its immediate environment and location.

Berger (1967) studied lightning discharges to mountain peaks and the surrounding area and has shown that both downward and upward propagating discharge channels occur and are influenced by the environment. Downward strokes are related to the presence of an intense space charge in the atmosphere and the region near the discharge termination. The path of the downward stroke is defined by the irregular, nonlinear, and variable distribution of the space charge. The space charge is apparently influenced by the topography, wind, and air conductivity, but not by soil conductivity.

Upward propagating lightning strokes are more influenced and controlled by the electric field near the point of origin. Space charge and soil conductivity are speculated to be of prime importance in the development of the stroke. The upward stroke begins with a relatively long-duration current flow of about 100 A, in contrast to the short-impulse current of a downward stroke.

Golde (1967) discussed the downward leader stroke tip and the development of the current flow, and the electric field variation between the tip and ground. The lightning current can rise from zero to its peak value in a few microseconds and decay much more slowly, requiring

perhaps several hundred microseconds. The rate of increase with time of the voltage to ground of the tip of the leader stroke was given as

$$\frac{dV}{dt} = 1.8 \times 10^7 \frac{q}{vt^2} \exp(-\beta vt) \qquad (7.6)$$

where q is the charge of the channel, usually 1 C (the electron charge is 1.6×10^{-19} C), $\beta \simeq 10^{-5}$, v is the propagation velocity, say 1.5×10^7 cm sec^{-1}, and $h \cong vt$ is the height of the tip above ground at time t. At $h \cong 100$ m, the rate of voltage rise would be 24 kV μsec^{-1}. The breakdown voltage for normal air is ~12 kV cm^{-1}. It is reasonable, then, to expect that air breakdown occurs quite rapidly with the downward leader stroke.

Should the electric field not fully develop due to moderating space charge influences in the atmosphere or ground related aspects, then flashless discharges may occur. It is not clear whether flashless discharges constitute a general upward or downward current flow. Flashless discharges apparently occur rapidly and transfer a relatively large current. Tomlinson (1888a–c) discussed a flashless discharge occurrence which caused the deaths of several people and animals. No discharge was noticed by the nearby observers. Yet evidence of a high-current discharge was verified by examination of the immediate area.

Upward large current discharges from ground were also reported by Fieux, Gary, and Hubert (1975) as a result of their investigations into the study of triggered lightning. The discharges were visible, not flashless, but caused a luminous residue to remain after the main discharge dissipated. It was noted that the geometry and conditions of the ground surface influenced the appearance of the luminous residue. A similar luminous residue was reported by Norinder (1939). A luminous globe was observed to have developed from what appeared to have been a downward-propagating stroke.

It is not inconceivable that a localized discharge could give rise to a luminous phenomenon similar to that excited by the radiofrequency-discharge experiments of Powell and Finkelstein (1969, 1970). They postulated the formation of natural atmospheric ball lightning based upon their experimental results. A luminous ball similar to the experimental phenomenon but produced in nature should last 0.5–1.0 sec if energy were concentrated in a small air volume by a stroke and stored in molecular electronically excited states. The ball so produced could become positively charged in a postdischarge field of 1–2 kV cm^{-1}, and its lifetime could be extended to about 1 sec.

If the imposed electric field were directed towards the ground, then an electrohydrodynamical force could cause the positively charged

ball to move downwards or against the wind. The positive ion space charge could be attracted to conductors in the vicinity and cause movement, possibly through openings or windows. An explosive decay might result if a small portion of the ball experienced rapid heating, possibly induced by contact with a conductor due to the sudden electron current flow.

The luminous phenomenon was described by Powell and Finkelstein (1969, 1970) as being composed of three regions. A central volume where Townsend multiplication occurs would have a fairly uniform temperature and would be the source of the visible radiation. An intermediate region or boundary layer where the temperature decreases radially would provide the transition between the core and the surrounding ambient air. The third region was the surrounding air. A schematic of the model is shown in Figure 7.18.

Townsend multiplication should occur within the ball producing more electron and ion pairs. A positive ion and electron current flowing out of the ball would develop in response to the electric field forces. As electron mobility is greater than that of an ion, the net charge density would be expected to soon become positive. Additional electrons would then be channeled back into the ball from the surrounding medium. Electron-impact excitation of air molecules may replenish the internal energy storage as excited molecules decay and emit light.

An estimation of the charge excited molecular density may be made from a few assumptions about such a luminous ball. Assume a core diameter of 10 cm (4 in) yellow (6000 Å) emissions, and a radiated power of 50 W with uniform emission and a lifetime of 1.0 sec. This would require an excited molecular density of about 3×10^{17} cm^{-3}. The density of the CO_2 molecules in normal air is about 1×10^{16} cm^{-3}. Since the visible radiation would be from that molecule, it is clear that continuous excitation of the CO_2 molecules from the energy storage molecules is required. A shorter life of $\simeq 0.1$ sec would result if no continuous energy transfer were to occur.

Powell and Finkelstein calculated that the current flow required to sustain a ball with a radiated power of order 100 W would be about 20 mA at 2000 V cm^{-1}. It was assumed that such small currents would be easily available. Corona and persistent lightning discharges, for example, could produce the required currents.

Ette (1966) experimentally demonstrated a 30-μA corona discharge from a small bush 46 cm (18 in) in height which was placed in a field gradient of 240 V cm^{-1}. By extension, a 10-mA current should be produced by a field of 2000 V cm^{-1}. The discharge depends mainly on the electric field strength at the discharge point and is not dependent

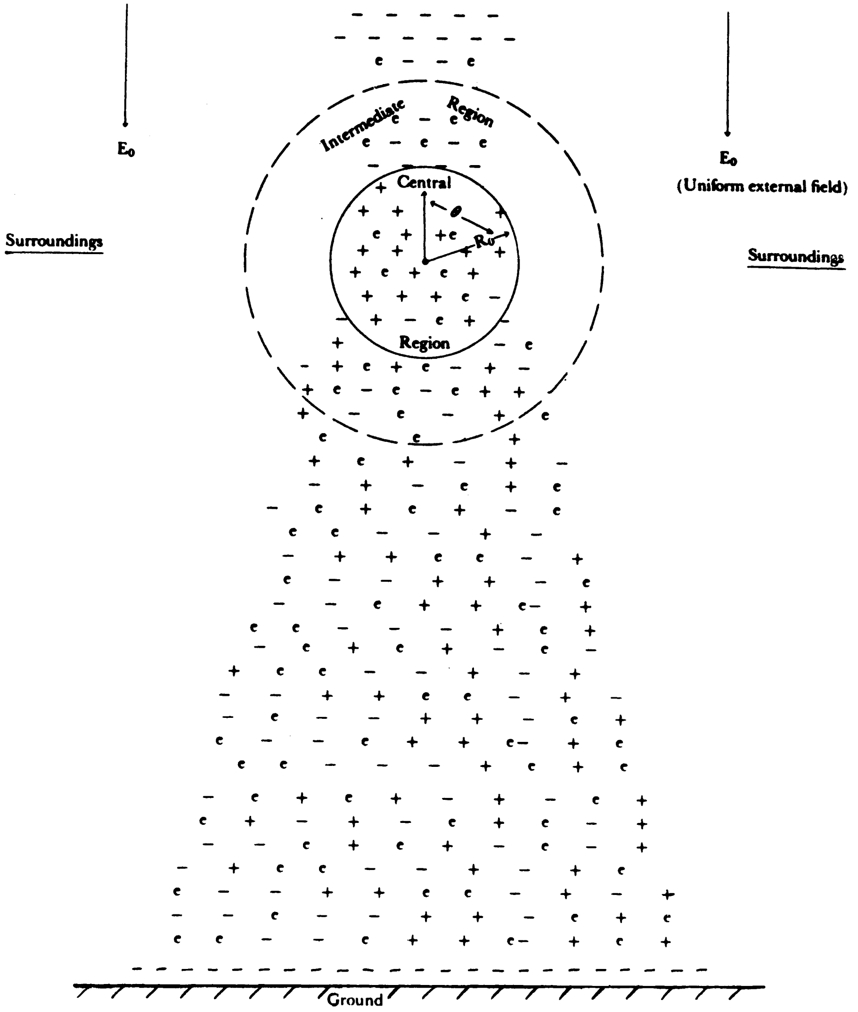

Figure 7.18. Schematic of the model proposed by Powell and Finkelstein (1969) to explain the long-lived luminous ball-lightning-like phenomenon excited by focused radiofrequency energy. Reproduced with permission from J. R. Powell and D. Finkelstein, "Structure of Ball Lightning," *Advances in Geophysics,* **13,** 1969, p. 141. A similar photograph was published by J. R. Powell and D. Finkelstein, "Ball Lightning," *American Scientist,* **58,** 1970, p. 262.

upon the presence of a space charge. The discharge current for multiple point discharges is given by

$$I = V \sum_{r=1}^{n} K_r(V - V_{0r}) \tag{7.7}$$

where V_{0r} is the potential required for the start of emission at the rth point and K_r is a constant which depends upon the geometry of the point, its position in the electric field, and the ionic mobility.

Brook, Kitagawa, and Workman (1962) found that lightning discharge currents can persist after the main stroke. Currents of 38–130 A were found to last as long as 0.3 sec after the stroke. The average negative charge transferred to ground was 34 C for hybrid flashes and 19 C for discrete flashes.

It is the opinion of many investigators that the experimental results of Powell and Finkelstein (1969, 1970) were the most significant in the history of this type of investigation. The results have certainly verified the probable existence of a natural luminous phenomenon, a ball lightning. The most important result is that normal air at atmospheric pressure may be excited, may store energy within its molecules, and may continue to exist as a luminous object for a finite period after the energy source has been terminated.

However, to my knowledge, direct current discharge excitation of air molecules producing the same localized illumination result as that from the radiofrequency experiments has not been reported. A natural excitation may have been recorded by Eriksson (1977a) although the luminous phenomenon lasted only 20–40 msec rather than about 0.5–1 sec. Excitation of vibrational states in the CO_2 molecule by direct electron discharge at low and atmospheric pressures is well known and is responsible for certain CO_2 lasers. The process produces 10 μm wavelength emissions but not visible light. The responsible energy transfer process which could produce visible light must be the subject of further study and experimentation.

In spite of these reservations, it would not be prudent to dismiss any possible excitation source mechanism such as a localized atmospheric discharge. Such a discharge could be quite localized, perhaps having dimensions not much larger than that of a normal discharge channel. Uman (1964) measured lightning discharge channel dimensions as having two principal values, 2–5 mm and 2–5 cm. If only a few joules were deposited in a volume of those dimensions, then molecular excitation as in O_2 and CO_2 would be expected.

The molecular excitation model of Powell and Finkelstein is similar to an earlier one by Finkelstein and Rubenstein (1964), and somewhat

similar to that of Cerrillo (1943), Kapitza (1955, 1961), and others. The model proposed by Kapitza has been widely discussed by many investigators and provided much of the stimulus for ball lightning research in the last few decades. Kapitza suggested that one means by which a luminous sphere could exist in the atmosphere for the period of time associated with ball lightning would be by the absorption of energy from an external source. The input energy was speculated as being from intense natural radiofrequency waves.

Kapitza based his arguments upon his understanding of plasma–electromagnetic-field interactions. A plasma cloud may absorb electromagnetic oscillations whenever a resonance exists between the wavelength and the diameter of the ball. The wavelength is then related to the ball diameter by

$$\lambda \leq 3.65d \tag{7.8}$$

If electromagnetic waves were incident upon a conducting surface, wave reflection would occur, and a standing wave could be established. The antinodes of the standing wave pattern would be established at regular intervals, $m\ \lambda/4$, where m is an odd integer. The field strength would be greatest at the antinode position.

The question of whether the plasmoid occurs at a field antinode or node was the subject of some debate. Watson (1960) predicted, from a mathematical treatment of the problem, that the plasmoid should occur at the field node rather than at the antinode. Tonks (1960) showed that, because of radiation and atmospheric pressure, the ball must come to equilibrium position at a field node even though the initial ionization begins at an antinode. Babat (1947) was able to form and maintain electromagnetic field discharges at either the field node or antinode. Other mathematical evaluations and discussions have been given by Silberg (1961a,b; 1965).

Kapitza assumed that the plasmoid volume is initially small compared to $d^3/6$, where d is the final ball diameter—about 10 cm. The ball ionization increases as a result of the plasmoid–electric-field resonance condition. This causes increasing absorption of energy by the plasmoid, which leads to ball expansion. As the plasmoid expands, a deviation from the resonance condition occcurs; the plasmoid then cools and returns to its resonance diameter. The resonance conditions maintain the ball diameter.

Since the diameter of natural ball lightning is about 10 cm (4 in.), the wavelength of the natural electromagnetic oscillation necessary to produce such a ball would be about 35 cm or a frequency of about 0.9 $\times\ 10^9$ Hz. Kapitza (1969a), Kosarev and Serezhkin (1974), and Kosarev,

Vaganov, Zakirov, Luganskii, Narusbek, and Samosyuk (1969), and Randjeloric (1969) investigated the occurrence of narrow-band radiation from natural lightning. They found relatively narrow-band radiation at frequencies near (0.1–0.2) $\times$ 10^9 Hz. The duration of the oscillations was, on the average, about 50 nsec, and they occurred 0.1–0.4 sec after the leader stroke appearance. The power spectral density was low, of order, 10^{-12}–10^{-10} W m^{-2} Hz^{-1} at a distance of 1 km from the lightning. The results did not verify that such oscillations in nature are intense enough to produce a Kapitza-type fireball. It was speculated, however, that the radiofrequency power might be quite large in the vicinity of the ionized lightning channel.

Although Kapitza (1955, 1961) is generally credited with the proposal of the external-energy-source model, Marchant (1930) made a similar, although general, suggestion 25 years earlier. His suggestion was an attempt to explain an observation of a ball lightning within a room. The ball lightning was observed to form and remain motionlesss near a metal doorknob in the room. It was noted that telephone wires ran from outside the house along two walls of the room and near the door. Marchant suggested that high-frequency standing waves were induced in the leads by a lightning discharge. He reasoned that if an electromagnetic pressure minimum were created between the wire and the knob, a ball lightning phenomenon might form at that point.

A similar proposal that ball lightning was related to some natural electromagnetic field oscillation within a room cavity was suggested by Cerrillo (1943) but remained largely unknown until the late 1950s. De Jans (1912a–c) also made reference to the standing electromagnetic wave concept, crediting Professor Lodge. Kapitza's work occurred at a time when scientific progress allowed experimental investigation, and it has become recognized as a significant concept in this field of investigation.

In conclusion, based upon the data and facts presently available, I believe that the atmospheric luminous phenomena denoted as ball lightning and bead lightning exist. I believe that the laboratory and/or controlled experiments in air have conclusively proven the ability to produce self-contained, luminous, long-lived regions of air or doped air which appear to possess the characteristics reported for ball lightning and bead lightning. I believe that a few photographs of natural and artificial atmospheric electrical phenomena have been correctly interpreted and provide definitive evidence for the existence of ball lightning and bead lightning phenomena. I believe that the phenomena have a relatively low temperature. The phenomena may not be regarded as classical plasmas with fully ionized medium characteristics. The electron

and ion density must also be rather low. I believe that the energy for the phenomena is stored as molecular excitation in metastable levels and is responsible for the relatively long life. The term "molecular electroluminescence" may be appropriate. I believe the phenomena are electrical in the sense that atmospheric electrical discharge activity is most likely to be responsible for their formation.

I recognize that these statements might be proven wrong by future work and more data. However, I hope this work serves to encourage further research and experimentation into the formation, production, and stability of the phenomena.

> The Road goes ever on and on
>   Down from the door where it began.
> Now far ahead the Road has gone,
>   And I must follow, if I can,
> Pursuing it with eager feet,
>   Until it joins some larger way
> Where many paths and errands meet.
>   And whither then? I cannot say.
>
> *J.R.R. Tolkien*
> *The Fellowship of the Ring*
> *Ballantine Books, New York*
> *1965*

8

Bibliography

8.1. Journals and Periodicals

Most observational reports, references, and discussions about the ball lightning and bead lightning phenomena may be found in numerous scientific journals and periodicals published during the past 300 years. These journals represent the main source of information for investigators interested in the phenomena. Many of these journals are readily available at the libraries of large universities. Others are more difficult to locate because of indexing variations and changes in titles and affiliations. The title abbreviations used by many authors and journals are not always recognizable by the investigator since a standard abbreviation has not been consistently used over the years. Many abbreviations used are not in agreement with the Chemical Abstracts Service Source Index Standard.

A number of journal abbreviations encountered during this investigation were unfamiliar and led to some difficulty in locating the reference. A few are discussed here to aid other researchers in their investigations. *Ann. Physik* is used for *Annalen der Physik,* which is also frequently referenced as *Ann. Poggendorff, Poggendorff's Annalen, Wied. Ann., Wiedemann's Annalen,* and *Drude's Annalen. Bull. Assoc. Sci. Fr.* is used for the *Bulletin de la Société Astronomique de France,* which was also referenced as *L'Astronomie* as the name was changed in 1911. Some confusion exists as a result of many errors and inconsistencies in volume and year values printed. *Le Cosmos* was used to refer to the *Revue des Sciences et leurs Applications, Paris,* and also referenced as *Kosmos* and *Le Monde.* The journal should not be confused with *Kosmos—Handweiser für Naturfreunde. Elektro. Zeit.* was used for the *Elektrotechnische Zeitschrift,* which was occasionally referenced as *ETZ* and *Elekt. Zeit.,* but references to *Elekt. Zeit.* prior to 1880 do not refer to *Elektrotechnische Zeitschrift.*

Gao or *Gaea* refers to *Der Ursprung der Meteoriten Geo (Gaea). Isis* refers to *Gesellschaft Isis in Dresden.* The *Journal de Physique* has had several titles, *Journal de Physique, Teorique et Appliquee* and *Journal de Physique et le Radium,* and abbreviations of each name have been used. *Klein's Wochen.* was used for *Klein's Wochenschrift fur Astronomie, Meteorologie und Geographie. Orion* is used for the *Schweizerische Astronomische Gesellschaft, SocieteAstronomique de Suisse. Sitz. Akad. Wiss.* refers to the *Sitzungsberichte, Akademie der Wissenschaften in Wien, Mathematisch-Naturwissenschaftliche Klasse. Syman's Met. Mag.* was used to refer to the *Meteorologische Magazine. Zeit. Deut. Met. Ges.* was occasionally used to refer to the *Zeitschrift der Deutschen Meteorologischen Gesellschaft,* which is one of the proper titles of the *Meteorologische Zeitschrift. Zh. Russ. Fiz. Khim. Obsh.* was used to refer to the *Zhurnal Russkago Fiziko-Khimicheskago Obshestva.*

8.2. Ball Lightning, Bead Lightning, and Related References

The bibliography herein serves several purposes and functions. It provides a listing of all references to ball lightning and bead lightning known to the author and includes the non-ball-lightning and non-bead-lightning references used in the various chapters. The list of ball lightning and bead lightning references represents the most complete list of such references available and as such is indispensable as a research tool. The study of relatively unknown and occasionally misunderstood natural phenomena relies on past reports and observations for clues about the true nature of the events.

Most references to ball lightning and bead lightning appear as first-person reports, discussions, scientific evaluations, or experimental descriptions. Many of the references have appeared in various periodicals, single publications, or in the scientific literature during the past 300 years. A number of these publications have been readily available, while others have not. Over 1600 references to ball lightning and bead lightning have been accumulated and are listed herein. Most have been personally inspected and verified by this author.

Some references were found to be incomplete, having been originally noted in some of the older journals. Many of these references have been considered by other authors as authentic, but were unavailable for personal verification by this author. These unverified references are denoted by the words "UNAVAILABLE—TITLE UNKNOWN" or followed by an asterisk if the title is known and included for

completeness. Other investigators may have access to such journals so far unavailable to this author and could extend the usefulness of the bibliography.

All references used in the text were also included in the bibliography. Some refer, of course, to ball lightning and bead lightning, while others do not. The references that do not refer to ball or bead lightning were needed to complete the discussions and further the aims of the chapters. These references were therefore included but distinguished by the notation (NBL) to avoid confusion.

I maintain the reference file on computer cards and memory disk, and will expand the list continuously. I welcome additions or corrections.

ABBOT, C.G., "REMARKABLE LIGHTNING PHOTOGRAPHS", SMITHSONIAN MISCELLANEOUS COLLECTIONS, 92,NO.12,1934

ADAMSON, D.F., "NOTES ON A CURIOUS LIGHTNING FLASH", ELECTRICIAN, 25,1890,PG.445

ALCANTARA, P., "PRIE COMMUNIQUER ACADEMIE CHUTE FOUDRE GLOBULAIRE, MINAS, 16 SEPTEMBRE", C.R.HEBD.SEANCES ACAD.SCI., 109,1889a,PG.496

ALCANTARA, P., "LA FOUDRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 111,1890b,PG.496

ALCANTARA, P., "UNAVAILABLE-TITLE UNKNOWN", NATURWISS.RUND., 22,1890,PG.284

ALEXANDER, W.H., "A POSSIBLE CASE OF BALL LIGHTNING", MON.WEATHER REV., 35,1907,

ALGEO, J. AND T.PYLES, "COMMENTS IN THE ANGLO-SAXON CRONICLE, JAN.793 A.D.", AS REFERENCED IN "PROBLEMS IN THE ORIGIN AND DEVELOPMENT OF THE ENGLISH LANGUAGE", HARCOURT, BRACE AND WORLD, INC., NEW YORK, 1966,PG.126

ALIVERTI, G. AND G.LOVERA, "UEBER EINIGE IN OBERITALIEN BERICHTETE KUGELBLITZE", ARKIV FOER METEOROL.GEOPHYSIK UND BIOKLIMAT., A3,1950,PG.77

ALLIBONE, T.E., "MULTIPLE LIGHTNING STROKES", AMER.METEOROL.SOC.Q.J., 70,1944, PG.161

ALT, E., "KUGELBLITZ", METEOROL.ZEIT., 18,1901,PG.573

ALTSCHULER, M.D., "ATMOSPHERIC ELECTRICITY AND PLASMA INTERPRETATIONS OF UFO'S", IN "SCIENTIFIC STUDY OF UNIDENTIFIED FLYING OBJECTS", E.U.CONDON-ED., E.P. DUTTON, NEW YORK, 1969, CHAP.7,PG.723

ALTSCHULER, M.D., L.L.HOUSE AND E.HILDNER, "IS BALL LIGHTNING A NUCLEAR PHENOMENON?", NATURE, 228,1970,PG.545

ANDERSEN, W.H., "ENERGY SOURCE FOR BALL LIGHTNING", J.GEOPHYS.RES., 70,1965, PG.1291

ANDERSEN, W.H., "REPLY", J.GEOPHYS.RES., 71,1966,PG.680

ANDERSON, F.J. AND G.D.FREIER, "A REPORT ON BALL LIGHTNING", J.GEOPHYS.RES., 77, 1972,PG.3928

ANDERSON, R., S.BVEINBJORN, D.C.BLANCHARD, S.GATHMAN, S.JONASSON, C.B.MOORE, H.J.SURVILAS, AND B.VONNEGUT, "ELECTRICITY IN VOLCANIC CLOUDS", SCIENCE, 14, 1965,PG.1179 (NBL)

ANDREW, W.L., "BALL LIGHTNING AT CATTEWATER", METEOROL.MAG., 62,1927,PG.186

ANDRIANOV, A.M. AND V.I.SINITSYN, "UNAVAILABLE-TITLE UNKNOWN", PREPRINT NO. IAE-2719, I.V.KURCHATOV INSTITUTE OF ATOMIC ENERGY, MOSCOW, USSR, 1976

ANDRIANOV, A.M. AND V.I.SINITSYN, "EROSION-DISCHARGE MODEL FOR BALL LIGHTNING", SOV.PHYS.TECH.PHYS., 22(11),1977a,PG.1342

ANDRIANOV, A.M. AND V.I.SINITSYN, "ISPOL'ZOVANIE EROZIONNOGO RAZRIADA DLIA MODELIROVANIIA ODNOGO IZ VOZMUZHNYKH VIDOV SHAROVOI MOLNII", ZH.TEKH.FIZ., 47, 1977b,PG.2318

ANGSTROM, C.A., "UNAVAILABLE-TITLE UNKNOWN", OVFERSIGT KONGL.VETENSKAPS-AKADEM. FORHANDL.(STOCKHOLM), 40,1883,PG.87

ANIOL, R., "DER KUGELBLITZ, EINE BIBLIOGRAPHIE", METEOROL.RUND. 7,1954,PG.220

ANON, , "A NARRATIVE OF DIVERS ODD EFFECTS OF A DREADFUL THUNDER-CLAP, AT STRALLUND IN POMERANIA, 19/29 JUNE 1670", ROY.SOC.LOND.PHIL.TRANS., 5,1670, PG.2084

ANON, , "SOME REMARKABLE EFFECTS OF A GREAT STORM OF THUNDER AND LIGHTNING AT PORTSMOUTH, OCT.23,1685", ROY.SOC.LOND.PHIL.TRANS., 16,1692,PG.1212

ANON, , "AN ACCOUNT OF THE DEATH OF MR. GEORGE WILLIAM RICHMANN, PROFESSOR OF EXPERIMENTAL PHILOSOPHY, A MEMBER OF THE IMPERIAL ACADEMY OF SCIENCES AT PETERSBURG", TRANSLATED FROM HIGH DUTCH, ROY.SOC.LOND.PHIL.TRANS., 49,1755.PG.61

ANON, , "UNAVAILABLE-TITLE UNKNOWN", COUR.PHYS.EXPR.MATH., 3,1769,PG.405

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ROY.SOC.LOND.PHIL.TRANS., 2,1773,PG.231

ANON, , "A SHORT VIEW OF THE NEW ELECTRICAL EXPERIMENTS PERFORMED BY DR. VAN MARUM", PHIL.MAG., 8,1800,PG.313

ANON, , "UNAVAILABLE-TITLE UNKNOWN", NATURWISS., 3,1836,PG.264 (*)

ANON, , "FEUERKUGELN", (SUMMARY), FORTSCHR.PHYS., 2,1846,PG.202

ANON, , "BEOBACHTETE PHANOMENE-FEUERKUGLN", (SUMMARY), FORTSCHR.PHYS., 3,1847, PG.169

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ANNALS OF NOTTINGHAMSHIRE, 2,1853,PG.47

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ANNALS OF NOTTINGHAMSHIRE, 2,1853,PG.157

ANON, , "UNAVAILABLE-TITLE UNKNOWN", KLIMA.BEIT.GES.STUR.BERLIN, 7,1857,PG.221

ANON, , "CAS DE FOUDRE EN BOULE A BRIGHTON", COSMOS, 17,1860a,PG.29 (*)

ANON, , "COUPS DE FOUDRE MYSTERIEUX; FOUDRE EN BOULE", COSMOS, 17,1860b,PG.718 (*)

ANON, , "CAS DE FOUDRE EN BOULE A BRIGHTON", (SUMMARY), FORTSCHR.PHYS., 16,1860c, PG.624

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 16,1860d,PG.281

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 18,1861a,PG.1

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 18,1861b,PG.758

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 21,1862,PG.141

ANON, , "COUPS DE FOUDRE MYSTERIEUX; FOUDRE EN BOULE", (SUMMARY), FORTSCHR.PHYS., 16,1864,PG.624

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 21,1866,PG.199

ANON, , "BALL LIGHTNING", NATURE, 15,1877,PG.539

ANON, , "BEOBACHTUNGEN UBER KUGELBLITZE", AUSLAND, 51,1878a,PG.771 (*)

ANON, , "KUGELBLITZ BEOBACHTET IN DANEMARK", GAEA, 14,1878b,PG.61 (*)

ANON, , "KUGELBLITZ BEOBACHTET IN DANEMARK", (SUMMARY), FORTSCHR.PHYS., 34(6), 1878c,PG.1156

ANON, , "BEOBACHTUNGEN UBER KUGELBLITZE", (SUMMARY), FORTSCHR.PHYS., 34(6),1878d, PG.1163

ANON, , "GLOBULAR LIGHTNING", J.FRANKLIN INSTITUTE, 105,1878e,PG.203

ANON, , "SINGULAR PHENOMENON AT LOWER CUMBER", LONDONDERRY SENTINEL, JUNE 1,1878, ROYAL METEOROL.SOC.Q.J., 4,1878f,PG.281

ANON, , "GLOBULAR LIGHTNING", ELECTRICIAN, 5,1880,PG.1

ANON, , "LA FOUDRE EN BOULE", CIEL ET TERRE, 5,1884a,PG.115

ANON, , "LA FOUDRE EN BOULE", CIEL ET TERRE, 5,1884b,PG.365

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ENGLISH MECH., 1 APRIL, 1884c

ANON, , "PHYSICAL NOTES", NATURE, 30,1884d,PG.569

ANON, , "UNAVAILABLE-TITLE UNKNOWN", VER.KAYSER.MONAT.BERLIN AKAD., NOV.1884e, PG.613

ANON, , SUMMARY OF "UEBER DEN GEGENWARTIGEN STAND DER KUGELBLITZ-FRAGE" FROM METEOROL.ZEIT., MARCH,1885,PG.118, IN AMER.J.METEOROL., 2,1885a,PG.142

ANON, , "SPECIAL CORRESPONDENCE", ELECTRICIAN, 14,1885b,PG.433

ANON, , "UN CAS CURIEUX DE FOUDRE EN BOULE", (SUMMARY), FORTSCHR.PHYS., 41(3), 1885c,PG.652

ANON, , "GLOBULAR LIGHTNING", J.FRANKLIN INSTITUTE, 119,1885d,PG.143

ANON, , "UN CAS CURIEUX DE FOUDRE EN BOULE", LA NATURE, 8,1885e,PG.190 (*)

ANON, , "ARTIFICAL BALL LIGHTNING", METEOROL.MAG., 20,1885f,PG.26

ANON, , "MASS OF FIRE FALLS INTO SEA", SCIENCE, 5,1885g,PG.242

ANON, , "FEU SAINT-ELME", CIEL ET TERRE, 6,1885/86,PG.70 (NBL)

ANON, , "GLOBULAR LIGHTNING", ELECTRICIAN, 17,1886a,PG.293

ANON, , "FATAL DISCHARGE OF GLOBULAR LIGHTNING", ELECTRICIAN, 17,1886b,PG.333

ANON, , "LA FOUDRE GLOBULAIRE", L'ASTRONOMIE, 5,1886c,PG.310 (*)

ANON, , "FOUDRE EN BOULE", L'ASTRONOMIE, 5,1886d,PG.432 (*)

ANON, , "LA FOUDRE GLOBULAIRE", METEOROLOGIE, 34,1886e,PG.310

ANON, , "LITERATURBERICHT", METEOROL.ZEIT., 3,1886f,PG.515

ANON, , "FEU SAINT-ELME", CIEL ET TERRE, 7,1886/87,PG.407 (NBL)

ANON, , "NOTE SUR UN COUP DE FOUDRE", BULL.SOC.ELECTR., 1887a,PG.350 (*)

ANON, , "NOTE SUR UN COUP DE FOUDRE", C.R.HEBD.SEANCES ACAD.SCI., 104,1887b,PG.143

ANON, , "GLOBE LIGHTNING IN FRANCE", ELECTRICIAN, 19,1887c,PG.134

ANON, , "GLOBULAR LIGHTNING", ELECTRICIAN", 19,1887d,PG.325

ANON, , "CURIOUS EFFECTS OF LIGHTNING", ELECTRICIAN, 19,1887e,PG.431

ANON, , "NOTE SUR UN COUP DE FOUDRE", ELETTR.MILANO, 1887f,PG.474 (*)

ANON, , "NOTE SUR UN COUP DE FOUDRE", FORTSCHR.ELEKTR., I,1887g,PG.392 (*)

ANON, , "NOTE SUR UN COUP DE FOUDRE", (SUMMARY), FORTSCHR.PHYS., 43(3),1887h, PG.573

ANON, , "UNAVAILABLE-TITLE UNKNOWN", L'ASTRONOMIE, 6,1887i,PG.107

ANON, , "NOTE SUR UN COUP DE FOUDRE", LA LUMIERE ELECTRIQUE", 24,1887j,PG.476 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 15,1887k,PG.90

ANON, , "PERLENBLITZ", LA NATURE, 3 SEPT.1887l

ANON, , "FOUDRE EN BOULE", METEOROLOGIE, 35,1887m,PG.18

ANON, , "FOUDRE EN BOULE", METEOROLOGIE, 35,1887n,PG.19

ANON, , "ANCIEN EXEMPLE DE FOUDRE EN BOULE", METEOROLOGIE, 35,1887o,PG.221

ANON, , "BALL LIGHTNING", NATURE, 37,1887p,PG.187

ANON, , "GLOBULAR LIGHTNING", NATURE, 37,1887q,PG.324

ANON, , "NOTE SUR UN COUP DE FOUDRE", REV.INTERN.ELECTR., 4,1887r,PG.107 (*)

ANON, , "GLOBULAR LIGHTNING", SCIENCE, 10,1887s,PG.324

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 4,1887t,PG.137

ANON, , "STRANGE LIGHTNING PHENOMENON AT GENEVA", ELECTRICIAN, 22,1888a,PG.5

ANON, , "GLOBE LIGHTNING", ELECTRICIAN, 22,1888b,PG.117

ANON, , "ECLAIRS EN BOULE A SAINT-PETERSBOURG", LA NATURE, OCT.1888c,PG.350 (*)

ANON, , "ECLAIR EN BOULE OBSERVE A MONTIVILLIERS EN 1720", LA NATURE, 16,DEC. 1888d,PG.6 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 37,1888e,PG.95

ANON, , "FOUDRE GLOBULAIRE", METEOROLOGIE, 36,1888f,PG.173

ANON, , "BEMERKENSWERTHE BLITZSCHLAGE", METEOROL.ZEIT., 5,1888g,PG.158

ANON, , "UNAVAILABLE-TITLE UNKNOWN", MITT.NATURWISS.VER.,STEIERMARK, 25,1888h, PG.228

ANON, , "NOTES", NATURE, 38,1888i,PG.238

ANON, , "UNAVAILABLE-TITLE UNKNOWN", SITZ.GENFER PHYS.GESELL., 20,DEC.,1888j

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 5,1888k,PG.94

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 5,1888l,PG.165

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 5,1888m,PG.166

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 5,1888n,PG.204

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 5,1888o,PG.208

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 5,1888p,PG.214

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ABHDLG.NATUR.VER.BREMEN, 13,1889a,PG.312

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ARCH.SCI.PHYS.NATUR., 21,1889b

ANON, , "GLOBULAR LIGHTNING", ELECTRICIAN, 22,1889c,PG.271

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ELEKTRO.ZEIT., 1,1889d,PG.7

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ELEKTRO.ZEIT., 1,1889e,PG.23

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ELEKTRO.ZEIT., 1,1889f,PG.28

ANON, , "SUR UN CAS DE FOUDRE GLOBULAIRE", (SUMMARY), FORTSCHR.PHYS., 45(3),1889g, PG.505

ANON, , "UNAVAILABLE-TITLE UNKNOWN", KOSMOS, 38,1889h,PG.142

ANON, , "UNAVAILABLE-TITLE UNKNOWN", KOSMOS, 38,1889i,PG.182

ANON, , "FOUDRE EN BOULE", L'ASTRONOMIE, 8,1889j,PG.312 (*)

ANON, , "SUR UN CAS DE FOUDRE GLOBULAIRE", LA LUMIERE ELECTRIQUE", 33,1889k, PG.143 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 17,1889l,PG.1

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 17,1889m,PG.334

ANON, , "FOUDRE GLOBULAIRE A MONTFORT-L'AMAURE", LA NATURE, 17,1889n,PG.383 (*)

ANON, , "ECLAIRS EN BOULE A SAINT-PETERSBOURG", METEOROLOGIE, 37,1889o,PG.23

ANON, , "FOUDRE GLOBULAIRE A MONTFORT L'AMAURY", METEOROLOGIE, 37,1889p,PG.192

ANON, , "COUPS DE FOUDRE EN BELGIQUE EN 1887", METEOROLOGIE, 37,1889q,PG.228

ANON, , "NOTES", NATURE, 41,1889r,PG.303

ANON, , "UNAVAILABLE-TITLE UNKNOWN", STAAT.WURT.FRIEDRICHSHAFEN, 163,16JULI,1889s

ANON, , "UNAVAILABLE-TITLE UNKNOWN", UBER LAND UND MEER, 32,1889t,PG.127

ANON, , "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 6,1889u,PG.68

ANON, , "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 6,1889v,PG.69

ANON, , "METEOROLOGISCHE NOTIZEN UND KORRESPONDENZEN", ZEIT.ANGEW.METEOROL., 6, 1889w,PG.119

ANON, , "REPRODUCTION DU PHENOMENE DE LA FOUDRE EN BOULE", CIEL ET TERRE, 11, 1890a,PG.424

ANON, , "UNAVAILABLE-TITLE UNKNOWN", EBENDA, 2,1890b,PG.298

ANON, , "NOTES", ELECTRICIAN, 26,1890c,PG.2

ANON, , "A SHOWER OF LIGHTNING", ELECTRICIAN, 5,1890d,PG.74

ANON, , "GLOBULAR LIGHTNING EXPERIMENTS", ELECTRICIAN, 26,1890e,PG.194

ANON, , "GLOBULAR LIGHTNING" ELECTRICIAN, 22,1890f,PG.413

ANON, , "FOUDRE GLOBULAIRE", LA NATURE, 18,1890g,PG.167

ANON, , "FOUDRE EN BOULE", METEOROLOGIE, 38,1890h,PG.246

ANON, , "UNAVAILABLE-TITLE UNKNOWN", MITTLG.NATUR.VER.STEINHEIM, 28,1890i,PG.348

ANON, , "UNAVAILABLE-TITLE UNKNOWN", MITTLG.NATUR.VER.STEINHEIM, 27,1890j,PG.423

ANON, , "NOTES(THE CAUCASUS PAPERS)", NATURE, 42,1890k,PG.458

ANON, , "METEOROLOGISCHE NOTIZEN UND KORRESPONDENZEN", ZEIT.ANGEW.METEORO}., 7, 1890l,PG.192

ANON, , "METEOROLOGISCHE NOTIZEN UND KORRESPONDENZEN", ZEIT.ANGEW.METEOROL., 7, 1890m,PG.212

ANON, , "UBER DIE KUGELBLITZ - ERSCHEINUNGEN DES TORNADOS VON SAINT-CLAUDE", ZEIT.ANGEW.METEOROL., 7,1890n,PG.288

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ELEKTRO., 8,1890o,PG.487

ANON, , "BLITZSCHLAG IN DIE KIRCHE ZU PREETZ", ELEKTR.ZEIT., 51,1891a,PG.5 (*)

ANON, , "REPRODUCTION DE L'ECLAIR EN BOULE", (SUMMARY), FORTSCHR.PHYS., 47(3), 1891b,PG.360

ANON, , "KUGELBLITZ IN BERGA BEI SCHLIEBER", GAEA, 27,1891c,PG.627

ANON, , "FOUDRE GLOBULAIRE A MONTFORT L'AMAURY", L'ASTRONOMIE, 5,1891d,PG.77 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", L'ASTRONOMIE, 5,1891e,PG.299

ANON, , "UNAVAILABLE-TITLE UNKNOWN", L'ASTRONOMIE, 5,1891f,PG.357

ANON, , "REPRODUCTION DE L'ECLAIR EN BOULE", LA NATURE, 19,1891g,PG.122 (*)

ANON, , "FOUDRE GLOBULAIRE A MONTFORT L'AMAURY", METEOROLOGIE, 39,1891h,PG.99

ANON, , "UNAVAILABLE-TITLE UNKNOWN", MITT.NATURWISS.VER.,STEIERMARK, 28,1891i, PG.334

ANON, , "UNAVAILABLE-TITLE UNKNOWN", MITT.NATURWISS.VER.,STEIERMARK, 28,1891j, PG.349

ANON, , "NOTES", NATURE, 44,1891k,PG.327

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 8,1891l,PG.165

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 8,1891m,PG.166

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 8,1891n,PG.214

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ELECTR.ENGR., DEC.25,1892a

ANON, , "KUGELBLITZ IN BERGA BEI SCHLIEBER", (SUMMARY), FORTSCHR.PHYS., 48(3), 1892b,PG.367

ANON, , "FOUDRE GLOBULAIRE", LA NATURE, OCT.,1892c,PG.286 (*)

ANON, , "ECLAIRS EN CHAPELET", LE COSMOS, JUIN,1892d,PG.319 (*)

ANON, , "LA FOUDRE GLOBULAIRE", LE COSMOS, JUIN,1892e,PG.319 (*)

ANON, , "ECLAIRS EN CHAPELET", METEOROLOGIE, 40,1892f,PG.217

ANON, , "FOUDRE GLOBULAIRE", METEOROLOGIE, 40,1892g,PG.252

ANON, , "A LIGHTNING STORY. BALL LIGHTNING", METEOROL.MAG., 28,1892h,PG.188

ANON, , "UNAVAILABLE-TITLE UNKNOWN", MITT.NATURWISS.VER.,STEIERMARK, 29,1892i, PG.427

ANON, , "NOTES", NATURE, 46,1892j,PG.548

ANON, , "KUGELBLITZ", METEOROL.ZEIT., 10,1893a,PG.157

ANON, , "UNAVAILABLE-TITLE UNKNOWN", TIDSKR.PHYS.CHEM., 2,1893b,PG.242

ANON, , "UNAVAILABLE-TITLE UNKNOWN", KOSMISCHE PHYS., 1894a,PG.80

ANON, , "ECLAIR EN BOULE", LA NATURE, JUIN,1894b,PG.47 (*)

ANON, , "ECLAIR EN BOULE", METEOROLOGIE, 42,1894c,PG.200

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ELEKTRO., 12,1894d,PG.73

ANON, , "UNAVAILABLE-TITLE UNKNOWN", VER.KGL.METEOROL.INST.BERLIN, 1895,PG.24

ANON, , "BEOBACHTUNG UBER KUGELBLITZE", (SUMMARY), FORTSCHR.PHYS., 52(3),1896a, PG.299

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 45,1896b,PG.387

ANON, , "ECLAIR EN BOULE", METEOROLOGIE, 42,1896c,P.200

ANON, , "BEOBACHTUNG UBER KUGELBLITZ", ZEIT,ANGEW.METEOROL., 13,1896d,PG.36 (*)

ANON, , "BEOBACHTUNG UBER KUGELBLITZ", ZEIT.ANGEW.METEOROL., 13,1896e,PG. 97 (*)

ANON, , "BEOBACHTUNG UBER KUGELBLITZ", ZEIT.ANGEW.METEOROL., 13,1896f,PG.215 (*)

ANON, , "BEOBACHTUNG UBER KUGELBLITZ", ZEIT.ANGEW.METEOROL., 13,1896g,PG.216 (*)

ANON, , "BEOBACHTUNG UBER KUGELBLITZ", ZEIT.ANGEW.METEOROL., 13,1896h,PG.262 (*)

ANON, , "BEOBACHTUNG UBER KUGELBLITZ", ZEIT.ANGEW.METEOROL., 13,1896i,PG.263 (*)

ANON, , "BEOBACHTUNG UBER KUGELBLITZ", ZEIT.ANGEW.METEOROL., 13,1896j,PG.264 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 46,1897a,PG.547

ANON, , "KUGELBLITZ", METEOROL.ZEIT., 14,1897b,PG.34

ANON, , "UNAVAILABLE-TITLE UNKNOWN", MITTLG.NATUR.VER.STEINHEIM, 34,1897c,PG.175

ANON, , "UNAVAILABLE-TITLE UNKNOWN", MITTLG.NATUR.VER.STEINHEIM, 34,1897d,PG.176

ANON, , "UNAVAILABLE-TITLE UNKNOWN", VERHDLGN.NAT.VER.BRUNN, 36,1897e,PG.41

ANON, , "ZWEI SELTSAME BLITZSCHLAGE", ZEIT.ANGEW.METEOROL., 14,1897f,PG.93 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 14,1897g,PG.144

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 14,1897h,PG.166

ANON, , "EIN KUGELBLITZ", ZEIT.ANGEW.METEOROL., 14,1897i,PG.167 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 14,1897j,PG.252

ANON, , "GEWITTER", (SUMMARY), FORTSCHR.PHYS., 54(3),1898a,PG.313

ANON, , "KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 54(3),1898b,PG.314

ANON, , "KUGELBLITZ", NATURGESCHICHTE MECKLENBURG, 52,1898c,PG.100 (*)

ANON, , "GEWITTER", ZEIT,ANGEW.METEOROL., 15,1898d,PG.70

ANON, , "UNAVAILABLE-TITLE UNKNOWN", MITTLG.NATUR.VER.STEINHEIM, 36,1899,PG.228

ANON, , "UEBER DIE BLITZ", ASTR.RUND., 2,1900a,PG.24 (*)

ANON, , "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 14,1900b,PG.510

ANON, , "L'ECLAIR EN BOULE", COSMOS, SEPTEMBRE,1900c,PG.287 (*)

ANON, , "NOTES-GLOBULAR LIGHTNING", ELECTRICIAN, 45,1900d,PG.587

ANON, , "UEBER DIE BLITZ", (SUMMARY), FORTSCHR.PHYS., 56(3),1900e,PG.253

ANON, , "UBER DEN KUGELBLITZ", METEOROL.ZEIT., 17,1900f,PG.382

ANON, , "NOTES", NATURE, 62,1900g,PG.350

ANON, , "A SHORT VIEW OF THE NEW ELECTRIC EXPERIMENTS PERFORMED BY DR. VAN MARUM", PHIL.MAG., 8,1900h,PG.193

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 17,1900i,PG.191

ANON, , "L'ECLAIR EN BOULE", (SUMMARY), FORTSCHR.PHYS., 57(3),1901a,PG.266

ANON, , "VERHEERUNG DURCH EINEN KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 57(3), 1901b,PG.266

ANON, , "VERHEERUNG DURCH EINEN KUGELBLITZ", GAEA, 37,1901c,PG.634

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 29,1901d,PG.2

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 29,1901e,PG.561

ANON, , "L'ECLAIR EN BOULE", METEOROLOGIE, 49,1901f,PG.53

ANON, , "OBSERVATION DE FOUDRE EN BOULE", METEOROLOGIE, 49,1901g,PG.353

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 18,1901h,PG.24

ANON, , "KUGELBLITZ IN ALTENBURG", (SUMMARY), FORTSCHR.PHYS., 58(3),1902a,PG.304

ANON, , "KUGELBLITZBEOBACHTUNG", METEOROL.ZEIT., 19,1902b,PG.335

ANON, , "KUGELBLITZ IN ALTENBURG", ZEIT.ANGEW.METEOROL., 19,1902c,PG.239 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ANN.HYDRO.MARIT.METEOROL., 32,1904a,PG.390

ANON, , "FOUDRE EN BOULE", L'ASTRONOMIE, 18,1904b,PG.378 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 21,1904c,PG.118

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 21,1904d,PG.119

ANON, , "SONDERBARE WIRKUNGEN EINES KUGELBLITZES", GAEA, 4,1905a,PG.57 (*)

ANON, , "LA FOUDRE EN BOULE", LA NATURE, 32,1905b,PG.258 (*)

ANON, , "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 20,1906a,PG.100

ANON, , "UNAVAILABLE-TITLE UNKNOWN", KOSMOS, 56,1906b,PG.309

ANON, , "NOCHMALS DER KUGELBLITZ 1896, REMSCHEID", PROMETHEUS, 18,1907,PG.576 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LA MAT.FULM., 7,1908a,PG.113

ANON, , "UNAVAILABLE-TITLE UNKNOWN", NATURWISS.RUND., 8,1908b,PG.62

ANON, , "UNAVAILABLE-TITLE UNKNOWN", UMSCHAU, 19,1908c,PG.304

ANON, , "ECLAIR EN BOULE", CIEL ET TERRE, 29,1908/09,PG.399

ANON, , "FIREBALLS", ENGLISH MECHANIC, AUG.13,1909a(*)

ANON, , "KUGELBLITZ BEI TREPTOW", (SUMMARY), FORTSCHR.PHYS., 65(3),1909b,PG.283

ANON, , "FOUDRE EN BOULE", REV.NEPHOLOG., 47,1909c,PG.370 (*)

ANON, , "KUGELBLITZ BEI TREPTOW", WELTALL, 9,1909d,PG.300 (*)

ANON, , "FOUDRE EN BOULE", CIEL ET TERRE, 30,1909/10,PG.417

ANON, , "FOUDRE EN BOULE", CIEL ET TERRE, 31,1910a,PG.385

ANON, , "FOUDRE EN BOULE", (SUMMARY), FORTSCHR.PHYS., 66(3),1910b,PG.364

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 59,1910c,PG.30

ANON, , "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 25,1911a,PG.262

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 60,1911b,PG.19

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 60,1911c,PG.692

ANON, , "LES ECLAIRS GLOBULAIRES", REV.NEPHOLOG., 6,1911d,PG.539 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", VER.KEL.METEOROL.INST.BERLIN, 231,1911e,PG.72

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 28,1911f,PG.161

ANON, , "UN CAS REMARQUABLE DE FOUDRE EN BOULE", CIEL ET TERRE, 33,1912a,PG.199

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 29,1912b,PG.199

ANON, , "METEOROLOGISCHE NOTIZEN UND KORRESPONDENZEN", ZEIT.ANGEW.METEOROL., 30, 1913,PG.213

ANON, , "UNAVAILABLE-TITLE UNKNOWN", UMSCHAU, 25,1914a,PG.762

ANON, , "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 31,1914b,PG.215

ANON, , "DAS WESEN DER KUGELBLITZ", METEOROL.ZEIT., 32,1915a,PG.416

ANON, , "UNAVAILABLE-TITLE UNKNOWN", UMSCHAU, 26,1915b,PG.229

ANON, , "BALL LIGHTNING", ELECTR.EXP., JAN.1916a,PG.68 (*)

ANON, , "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 65,1916b,PG.341

ANON, , "BALL LIGHTNING AT SALINA, KANSAS", MON.WEATHER REV., 47,1919a,PG.728

ANON, , "GLOBULAR LIGHTNING", ROY.ASTRO.SOC.CANADA J., 13,1919b,PG.299

ANON, , "BALL LIGHTNING SEEN AT ST. JOHN'S WOOD", METEOROL.MAG., 56,1921,PG.195

ANON, , "UNAVAILABLE-TITLE UNKNOWN", UMSCHAU, 26,1922,PG.587

ANON, , "NATURE OF BALL LIGHTNING", METEOROL.MAG., 58,1923,PG.259

ANON, , "ONWEDER OPTISCHE VERSCHIJNSELEN", NZ. IN NEDERLAND, AMSTERDAM, NO.81, 1924a (*)

ANON, , "BALL LIGHTNING", SCIENTIFIC AMERICAN, 130,1924b,PG.242

ANON, , "BALL LIGHTNING", ROY.ASTRON.SOC.CANADA J., 19,1925,PG.213

ANON, , "UNTITLED-BOOK REVIEW-ROY.NED.METEOROL.INST. NO. 81, 1924", METEOROL.MAG., 61,1926a,PG.197

ANON, , "KUGELBLITZE UND FOHN IN DER KRIM", METEOROL.ZEIT., 43,1926b,PG.33

ANON, , "KUGELBLITZ", METEOROL.ZEIT., 44,1927,PG.188

ANON, , "ELECTRICAL PHENOMENON NEAR WEYMOUTH", NATURE, 126,1930a,PG.262

ANON, , "HISTORIC NATURAL EVENTS", NATURE, 126,1930b,PG.262

ANON, , "BALL LIGHTNING", SCIENCE, 74,SUPPL.NO.1908,1931,PG.10

ANON, , "UNAVAILABLE-TITLE UNKNOWN", SOC.FRAN.ELECT.BULL., 2,1932,PG.865

ANON, , "BALL LIGHTNING PHENOMENON", SCIENCE, 78,SUPPL.NO.2026,1933,PG.9

ANON, , "BALL LIGHTNING-THREE DISCHARGES", ROY.ASTRO.SOC.CANADA, 28,1934,PG.144

ANON, , "ON THE PROBLEM OF BALL LIGHTNING", ROY.METEOROL.SOC.Q.J., 65,1939,PG.532

ANON, , "UNAVAILABLE-TITLE UNKNOWN", TEKHNIKA-MOLODEZHI, NO.8,1942,

ANON, , "NABETRACHTING OVER DE BOLBLIKSEM VAN LUTJEWOLDE", (RECONSIDERATION OF THE BALL LIGHTNING AT LUTJENOLDE) , HAMEL EN DAMPKRING, 49(9),1951,PG.158 (*)

ANON, , "THUNDERBOLTS: THE ELECTRIC PHENOMENON OF THUNDERSTORMS", METEOROL.MAG., 81,1952,PG.146

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 9,1955a,PG.62

ANON, , "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 9,1955b,PG.378

ANON, , "UNAVAILABLE-TITLE UNKNOWN", CIVIL AVIATION-RUSS., 9,1958,PG.32

ANON, , "INTERESTING OBSERVATION OF LIGHTNING", METEOROL.MAG., 89,1960a,PG.235

ANON, , "UNAVAILABLE-TITLE UNKNOWN", PRAVDA, MOSCOW, OCT.30,1960b,PG.3

ANON, , "SHAROVILE MOLNII", PRIRODA, NO.5,1962,PG.71

ANON, , "AWAIZIJA I KOSMONAWTIKA", BILDMESSG.UND LUFTBILDWES., 47(10),1964a, PG.94 (*)

ANON, , "KUGELBLITZ TRIFFT FLUGZEUG", NATURWISS.RUND., 17,1964b,PG.482

ANON, , "NEW THEORETICAL MODEL FOR BALL LIGHTNING", SCIENCE NEWS LETT., 86,1964c, PG.199

ANON, , "BALL LIGHTNING DUE TO A LEAK IN STORKE AT JOINT", SCIENCE NEWS LETT., 86, 1964d,PG.392

ANON, , "BALL LIGHTNING", POPULAR SCIENCE, 192,NO.6,1968,PG.14

ANON, , "UNAVAILABLE-TITLE UNKNOWN", IND.OCEAN MAR.OBS., 42,1972,PG.52

ANON, , "UNUSUAL WEATHER: BALL LIGHTNING IN A FEBRUARY THUNDERSTORM DOWN EAST IN MAINE", WEATHERWISE, 29,1975,PG.84

ANON, , "FIREBALLS, SOME FIREY, SOME DARK", J.METEOROL., 1(10),1976,PG.312

ANON, , "BALL LIGHTNING IN CANADA", J.METEOROL., 3(31),1978,PG.212

ARABADJI, W.I., "GROZA I GROZOVYYE PROTSESSY", MINSK, IZD-VO BELGOS-UNIVERSITETA IMENI V.I.LENINA, 1960 (*)

ARABADJI, W.I., "ON THE PROBLEM OF BALL LIGHTNING", J.GEOPHYS.RES., 81(36),1976, PG.6455

ARABADJI, W.I., "REPLY", J.GEOPHYS.RES., 82(24),1977,PG.3500

ARABADZHI, V.I., "ON THE ELECTRICITY OF THUNDERSTORMS", PRIRODA, NO.7,1947, PG.12 (*)

ARABADZHI, V.I., "K TEORII YAVLENII ATMOSFERNOGO ELEKTRICHESTVA", MINSKOGO GOSUDARSTVENNOGO PEDAGOGICHESKOGO INSTITUTA, NO.5,1956,PG.77 (*)

ARAGO, F., "SUR LE TONNERRE", ANNUAIRE AU ROI PAR LE BUREAU DES LONGITUDES, 1838, NOTICES SCIENTIFIQUES, PG.221 (*)

ARAGO, F., "OEUVRES COMPLETES", GIDE ET J.BAUDRY-ED., PARIS, 1854, TOME 4, "LE TONNERE", PG.38,50,211

ARAGO, F., "THUNDER AND LIGHTNING", PARIS, 1859 (*)

ARGENTEUIL, M., "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 14,1859,PG.672

ARGYLE, E., "BALL LIGHTNING AS AN OPTICAL ILLUSION", NATURE 230,1971,PG.179

ARGYLE, M., "ON THUNDER AND LIGHTNING", EDINBURGH NEW PHIL.J., 26,1838,PG.81

ARRHENIUS, S.A., "LEHRBUCH DER KOSMISCHEN PHYSIK I", S.HIRZEL, LEIPZIG,1903,PG.772

ARZIMOVICH, L.A., "ELEMENTARY PLASMA PHYSICS", BLAISDELL PUBL.CO., NEW YORK, CHAP. 4,1965

ASHBY, D.E.T.F. AND C.WHITEHEAD, "IS BALL LIGHTNING CAUSED BY ANTIMATTER METEORITES?", NATURE, 230,1971,PG.180

ASHMORE, S.E., "ON THE PROBLEM OF BALL LIGHTNING", ROY.METEOROL.SOC.Q.J., 66,1940, PG.194

ASKAR'GAN, G.A., M.S.RABINOVICH, M.M.SAVCHENKO, AND V.K.STEPANOV, "OPTICAL BREAK- DOWN FIREBALL IN THE FOCUS OF A LASER BEAM", JETP LETT., 5,1967,PG.121, TRANSLATION OF ZH.EKSP.TEOR.FIZ., 5,(5),1967,PG.150

ASPDEN, H., "BALL LIGHTNING ENIGMA", NEW SCIENTIST, 57,1973,PG.42

ASSMANN, J., "WIRBELGEWITTER", (SUMMARY), FORTSCHR.PHYS., 59(3),1902,PG.279

ASSMANN, J., "WIRBELGEWITTER", ZEIT.ANGEW.METEOROL., 20,1903a,PG.1 (*)

ASSMANN, J., "WIRBELGEWITTER", ZEIT.ANGEW.METEOROL., 20,1903b,PG.21 (*)

ATKINSON, B.W., "RIDDLE OF BALL LIGHTNING", GEOGRAPHICAL MAG., 41,1968,PG.204

AUDOIN, M., "KUGELBLITZ, BEOBACHTET IN DER TSCHADSEE-REGION", METEOROL.ZEIT., 30, 1913,PG.148

AULOV, A., "ON COURSE-BALL LIGHTNING", IZVESTIA, 28JULY,1973,PG.6 (*)

BABAT, G.I., "ELECTRODELESS DISCHARGES AND CERTAIN PROBLEMS ASSOCIATED WITH THEM", VESTNIK ELEKTROPROMYSHLENNOSTI, 2/3,1942 (*)

BABAT, G.I., "ELECTRODELESS DISCHARGES AND SOME ALLIED PROBLEMS", INST.ELECT.ENGR. J.(LONDON), 94,PT.3,1947,PG.27

BABAT, G.I., "VYSOKOCHASTOTNOYE PLAMYA", YUNYI TEKHNIK, NO.7,1957,PG.56 (*)

BABICK, M., "KUGELBLITZBEOBACHTUNG IN COTTBUS", ZEIT.METEOROL., 9,1955,PG.378

BABINET, M., "SUR UN CAS DE FOUDRE GLOBULAIRE", C.R.HEBD.SEANCES ACAD.SCI., 35, 1852,PG.1

BABINET, M., "COURS DE PHYSIQUE", JAMIN ET BARRY-ED, PARIS,GAUTHIER-VILLARS, 1881 PG.320 (*)

BACHA, M., "METEOROLOGISCHE NOTIZEN UND KORRESPONDENZEN", ZEIT.ANGEW.METEOROL., 7, 1890,PG.192

BADGER, R.M., A.C.WRIGHT AND R.F.WHITLOCK, "ABSOLUTE INTENSITIES OF THE DISCRETE AND CONTINUOUS ABSORPTION BANDS OF OXYGEN GAS AT 1.26 AND 1.065 μm AND THE RADIATIVE STATE OF THE ($^1\Delta_g$) STATE OF OXYGEN", J.CHEM.PHYS., 43,1965,PG.4345(NBL)

BAGOTE, A., "ECLAIRS EN BOULE", BULL.SOC.ASTRON.FR., 33,1919,PG.284

BAKER-BLOCKER, A., T.M.DONAHUE AND K.H.MANCY, "METHANE FLUX FROM WETLAND AREAS", TELLUS, 29(3),1977,PG.245 (NBL)

BAILEY, B.H., "BALL LIGHTNING", WEATHERWISE, 30(3),1977,PG.99

BAILEY, T., "EVENTS", ANN.NOTTINGHAMSHIRE, HISTORY-COUNTY NOTTINGHAM INCLUDING THE BOROUGH, SIMPKIN,MARSHALL AND CO., LONDON. 4.1775,PG.47 (*)

BAILEY, T., "EVENTS", ANN.NOTTINGHAMSHIRE, HISTORY-COUNTY NOTTINGHAM INCLUDING THE BOROUGH, SIMPKIN,MARSHALL AND CO., LONDON, 4,1794,PG.157 (*)

BALDIT, A., "SUR UN ECLAIR EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 158,1914,PG.1542

BALJASNI, W., "WIEDERHOLUNG PLANTE'SCHER VERSUCHE", BEIBL.ANN.PHYS., 23,1899a, PG.843

BALJASNI, W., "WIEDERHOLUNG PLANTE'SCHER VERSUCHE", J.ELEKTR., 7,1899b,PG.106 (*)

BALTIN, P., "UNAVAILABLE-TITLE UNKNOWN", PHOTOGR.MITT., 39,1902,PG.390

BALYBERDIN, V.V., "ESTIMATING THE ENERGY OF BALL LIGHTNING", SAMOLETOSTROYENIYE I TEKHNIKA VOZDUSHNOGO FLOTA, NO.3,1965,PG.102 (*)

BALYBERDIN, V.V., "INTERNAL ENERGY OF BALL LIGHTNING", FOREIGN SCIENCE BULL., 2(4),1966,PG.48

BALYBERDIN, V.V., "INVESTIGATION OF THE MECHANISM OF FORMATION OF AN IONIZED VORTEX CONFIGURATION IN THE ATMOSPHERE", SAMOLETOSTROYENIYE I TEKHNIKA VOZDASHNOGO FLOTA, NO.5,1966,PG.3, IN "STILL ANOTHER BALL LIGHTNING HYPOTHESIS", FOREIGN SCIENCE BULL., 3.NO.5,1967,PG.103

BALYBERDIN, V.V., "VERIFICATION OF THE CASE OF THE ORIGIN OF BALL LIGHTNING", J.APPL.MECH.TECH.PHYS., 16(6),1975,PG.946, ENGLISH TRANSLATION OF ZH.PRIKL. MEKH.TEKH.FIZ., 16(6),1975,PG.132 (*)

BARATOUX, M., "SUR UNE OBSERVATION DE FOUDRE EN BOULE FAIT EN AVION", METEOROLOGIE, 16,1952,PG.164

BARETTE, H., "FOUDRE GLOBULAIRE DU LUNDI 17 JUILLET 1865", (SUMMARY), FORTSCHR. PHYS., 21,1865a,PG.64

BARETTE, H., "FOUDRE GLOBULAIRE DU LUNDI 17 JUILLET 1865", MONDES, 8,1865b, PG.726 (*)

BARRY, J.D., "BALL LIGHTNING, A NATURAL PHENOMENON IN ATMOSPHERIC PHYSICS", M.S.THESIS, CALIF.STATE COLLEGE, LOS ANGELES, CALIFORNIA, 1966

BARRY, J.D., "BALL LIGHTNING", J.ATMOS.TERR.PHYS., 29,1967a,PG.1095

BARRY, J.D., "A MODEL FOR BALL LIGHTNING", WISS.ZEIT.ELEKTRO., 9,1967b,PG.202

BARRY, J.D., "LABORATORY BALL LIGHTNING", J.ATMOS.TERR.PHYS.,30,1968a,PG.313

BARRY, J.D., "FIREBALL, BALL LIGHTNING AND ST.ELMO'S FIRE", WEATHER, 23,1968b, PG.180

BARRY, J.D., "BALL LIGHTNING IN THE LABORATORY", WISS.ZEIT.ELEKTRO., 12,1968c,PG.7

BARRY, J.D., "LABORATORY BALL LIGHTNING", PRIRODA, NO.12,1969,PG.62

BARRY, J.D., "A COMPREHENSIVE BIBLIOGRAPHY OF BALL LIGHTNING REPORTS", AIR FORCE AVIONICS LAB TECHNICAL REPORT, AFAL-TR-73-348, JAN. 1974a, WRIGHT-PATTERSON AFB, OHIO

BARRY, J.D., "BIBLIOGRAPHY OF BALL LIGHTNING REPORTS", J.ATMOS.TERR.PHYS. 32, 1974b,PG.1577

BARRY, J.D., "FREQUENCY OF BALL LIGHTNING REPORTS", J.GEOPHYS.RES., 84(C1), 1979,PG.308

BARRY, J.D., W.E.BONEY AND J.E.BRANDELIK, "LASER EMISSION FROM HE-AIR-CH4 AND HE-AIR-C3H8 MIXTURES", APPL.PHYS.LETT., 18,1971,PG.15 (NBL)

BASS, R.W. AND R.K.GOLKA, "NIKOLA TESLA'S THEORY OF BALL LIGHTNING (COLORADO SPRINGS, 1899)", EYRING RESEARCH INSTITUTE, PROVO, UTAH, UNPUBLISHED, 1976

BATTAN, L.J., "THE THUNDERSTORM", NEW AMERICAN LIBRARY, NEW YORK, 1964,PG.101

BAUER, C., "EINE BLITZAUFNAHME", UMSCHAU, 42,1938,PG.710

BAUMAN, G., "PHOTOGRAPHISCHE AUFNAHME EINER BLITZKUGEL IN RIGA", METEOROL.ZEIT., 54,1937,PG.192

BAY, I., "SUR UN CAS DE FOUDRE EN BOULE OBSERVE LE 26 MAI 1907", BULL.SOC.ASTRON. FR., 22,1908a,PG.232

BAY, I., "OBSERVATION DE FOUDRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 146,1908b, PG.554

BAY, I., "KUGELBLITZ", METEOROL.ZEIT., 25,1908c,PG.468

BAY, I., "KUGELBLITZBEOBACHTUNG", PROMETHEUS, 20,1908d,PG.48 (*)

BAYET, L., "LA FOUDRE EN BOULE", CIEL ET TERRE, 5,1884/85a,PG.115

BAYET, L., "FOUDRE EN BOULE",CIEL ET TERRE, 5,1884/85b,PG.365

BEADLE, D.G., "A CURIOUS AFTER EFFECT OF LIGHTNING", NATURE, 137,1936,PG.112

BEASLEY, W.H., M.A.UMAN, B.C.EDGAR AND B.N.TURMAN, "CORRELATED SATELLITE OPTICAL AND GROUND-BASED ELECTRICAL AND MAGNETIC FIELD OBSERVATIONS OF LIGHTNING", PRESENTED AT THE AGU SPRING MEETING, APRIL 17-21,1978, MIAMI BEACH, FLA, ABSTRACT IN EOS-TRANS.AGU, 59(4),1978,PG.284 (NBL)

BECK, F.X., "DAS GEWITTER IN SAARBRUCKEN AM 26 JUNI 1928", METEOROL.BEOBACHTUNGEN DER WETTERWARTE SAARBR., II,1920,PG.2 (*)

BECK, F.X., "NACHLEUCHTEN EINES BLITZES ALS PERLSCHNUR", ZEIT.ANGEW.METEOROL., 44, 1927,PG.141

BECQUEREL, M. AND E.BECQUEREL, "TRAITE D'ELECTRICITE ET DE MAGNETISME", PARIS, 1, 1855,PG.415 (*)

BEHN, U., "UBER PHOTOGRAPHIEN VON PERLSCHNURBLITZEN", METEOROL.ZEIT., 20,1903, PG.379

BELLAY, M.DU, "UNAVAILABLE-TITLE UNKNOWN", L'ASTRONOMIE, 5,1886,PG.311

BENDORF, G., "ATMOSFERNOYE ELEKTRICHESTVO", LENINGRAD, 1934 (*)

BENEDICKS, C., "THEORY OF THE LIGHTNING-BALLS AND ITS APPLICATION TO THE ATMOSPHERIC PHENOMENON CALLED FLYING SAUCERS", ARKIV FOER GEOFYSIK, 2,1954,PG.1

BERG, H., "BEOBACHTUNG EINES PERLSCHNURBLITZES", ZEIT.ANGEW.METEOROL., 47,1930, PG.315

BERGER, K., "NOVEL OBSERVATIONS ON LIGHTNING DISCHARGES: RESULTS OF RESEARCH ON MOUNT SAN SALVATORE", J.FRANKLIN INSTITUTE, 283,1967,PG.478 (NBL)

BERGER, K., "KUGELBLITZ UND BLITZFORSCHUNG", NATURWISS., 60,1973,PG.485

BERGSTROM, A., "ELECTROMAGNETIC THEORY OF STRONG INTERACTION", PHYS.REV., D,3, 1973,PG.4394

BERLAGE, H.P., "VAN BLIKSEMBALLEN NAAR LICHTGEVENDE AARDAPPELS EN WEER TERUG", HAMEL EN DAMPKRING, 53,1955,PG.65 (*)

BERTHOLON, M., "DE L'ELECTRICITE DES METEORES", LYON, 2,1787,PG.27 (*)

BESNOU, M., "DE L'ETAT DE L'IODE DANS L'ATMOSPHERE, ET DE LA POSSIBILITE DE LA FORMATION DE L'IODURE D'AZOTE DANS LES ORAGES", MEM.SOC.SCI.NAT.CHERBOURG, 1, 1852,PG.103 (*)

BIGELOW, P., "ELECTRICAL STORM IN SOUTHERN CALIFORNIA", MON.WEATHER REV., 35,1907, PG.228

BJARNE-SOLAS, M., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 73,1959,PG.16

BLACKHOUSE, T.W., "REMARKABLE LIGHTNING FLASHES", NATURE, 60,1899,PG.520

BLACKMAN, G.D'ARCY, "A WATERSPOUT WITH FIREBALLS", METEOROL.MAG., 57,1922,PG.250

BLAIR, A.J.F., "MAGNETIC FIELDS, BALL LIGHTNING AND CAMPANOLOGY", NATURE, 243, 1973,PG.512

BLAKE, R., "THE WIZARD OF WENDOVER", MOUNTAIN WEST MAGAZINE, NOV.1977,PG.25

BLANC, E., "OBSERVATION D'ECLAIRS EN BOULE, SE FORMANT ET ECLATANT SANS BRUIT AU- DESSUS D'UNE COUCHE DE MIRAGES", C.R.HEBD.SEANCES ACAD.SCI., 84,1877a,PG.666

BLANC, E., "BALL LIGHTNING", NATURE, 15,1877b,PG.539

BLUMHOF, F., "KUGELBLITZ BEI HAGELWETTER", (SUMMARY), FORTSCHR.PHYS., 61(3),1905a, PG.324

BLUMHOF, F., "EIGENTUMLICHE LICHTERSCHEINUNG", METEOROL.ZEIT., 22,1905b,PG.132

BOGGS, E.M., "BALL LIGHTNING", MON.WEATHER REV., 26,1898,PG.565

BOLL, K., "FEUERKUGEL", ZEIT.ANGEW.METEOROL., 30,1913,PG.214

BOLL, K., "BEOBACHTUNG VON KUGEL-UND PERLSCHNURBLITZEN ZU JAMBOL (BULGARIEN)", ZEIT.ANGEW.METEOROL., 35,1918,PG.130

BOLL, K., "SCHNELLBEWEGTE KUGELBLITZ", ZEIT.ANGEW.METEOROL., 37,1920,PG.191

BON, G.LE, "L'EVOLUTION DE LA MATIERE", PARIS, 1905,PG.154 (*)

BONACINA, L.C.W., "THE WIDECOMBE CALAMITY OF 1638", WEATHER, 1,1946,PG.122

BONNEY, A., "APPEARANCE OF AIR BUBBLES AT REMENHAM, BERKSHIRE, JANUARY, 1871", AMER.METEOROL.J., 4,1888a,PG.149

BONNEY, A., "APPEARANCE OF AIR BUBBLES AT REMENHAM BERKSHIRE, JANUARY, 1871", ELECTRICIAN, 19,1887b,PG.179

BONNEY, A., "APPEARANCE OF AIR BUBBLES AT REMENHAM, BERKSHIRE, JANUARY, 1871", METEOROL.ZEIT., 22,1887c,PG.88

BOOT, H.A.H., S.A.SELF, AND R.SHERSBY-HARRIS, "CONTAINMENT OF A FULLY IONIZED PLASMA BY RF FIELDS", J.ELECT.AND CONTROL, 4,1958,PG.434

BORLASE, W., "AN ACCOUNT OF A STORM OF THUNDER AND LIGHTNING, NEAR LUDGRAN IN CORNWALL", ROY.METEOROL.SOC.PHIL.TRANS., 48,1753,PG.86

BORT, M.T.DE, "ECLAIR EN CHAPELET", METEOROLOGIE, 44,1896,PG.66

BOTLEY, C.M., "A FIREBALL IN 1792", METEOROL.MAG., 59,1925,PG.185

BOTLEY, C.M., "THE AIR AND ITS MYSTERIES", BELL PUBL., LONDON, PLATE X, 1938 (*)

BOTLEY, C.M., "THE WIDECOMBE CALAMITY", WEATHER 21,1966,PG.318

BOTLEY, C.M., "TORNADOES AND BALL LIGHTNING", J.METEOROL., 2(21),1977,PG.271

BOTLEY, C.M., "BALL LIGHTNING", J.METEOROL., 3(31),1978,PG.215

BOTTLINGER, K.F., "ZUR FRAGE NACH DER NATUR DER KUGELBLITZE", NATURWISS., 16,1928, PG.220

BOUGON, D., "METEOROLOGIE", BULL.SOC.ASTRON.FR., 11,1897,PG.430

BOUGON, D., "COUPS DE FOUDRE", BULL.SOC.ASTRON.FR., 15,1901,PG.303

BOUGON, D., "COMMUNICATIONS DIVERSES-UN CURIEUX CAS DE FOUDRE GLOBULAIRE", BULL. SOC.ASTRON.FR., 16,1902a,PG.264

BOUGON, D., "FOUDRE GLOBULAIRE", BULL.SOC.ASTRON.FR., 16,1902b,PG.420

BOUIN, M., "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 18,1861,PG.758

BOWMAN, J.E., "ST ELMO'S FIRE NEAR GLENCOE", WEATHER, 4,1949,PG.197 (NBL)

BOYS, H.A., "REMARKABLE LIGHTNING FLASH", METEOROL.MAG., 45,1910,PG.108

BRAND, W., "JAHRLICHE HORBARKEITSPERIODE DES GESCHUTZDONNERS UND SEINE GROSSTEN BISHERIGEN REICHWEITEN", METEOROL.ZEIT., 17,1917,PG.58

BRAND, W., "DER KUGELBLITZ", PROBLEME DER KOSMISCHEN PHYSIK, II/III, H.GRAND, HAMBURG, 1923

BRAND, W., "BALL LIGHTNING" NATIONAL AERONAUTICS AND SPACE

ADMINISTRATION, TECHNICAL TRANSLATION, F-13228, FEB.1971, B.BENNY, WASHINGTON D.C.

BRASCH, A., "VORLAUFIGE VERSUCHE ZUR ERZIELUNG EXTREMER ELEKTRISCHER POTENTIALE MITTELS DER ATMOSPHARISCHEN GEWITTERELEKTRIZITAT", NATURWISS., 16,1928,PG.115

BREMEN, H., "UNAVAILABLE-TITLE UNKNOWN", ABHANDL.NATURWISS.VER.BREMEN, 13,1896, PG.312

BRERETON, O.S., "ACCOUNT OF THE VIOLENT STORMS OF LIGHTNING AT EAST-BOURN, IN SUSSEX, SEPT.17, 1780", ROY.SOC.LOND.PHIL.TRANS., 71,1781,PG.42

BRESTER, A., "UNAVAILABLE-TITLE UNKNOWN", REV.GENERALE SCI., 21,1910,PG.385

BREVDEL, A., "NATURE INTIME DE L'ELECTRICITE, DU MAGNETISME ET DES RADIATIONS", BRUXELLES-PARIS, 1904,PG.20 (*)

BREW, W., "A PARTICULAR DISCHARGE OF LIGHTNING", NATURE, 48,1893,PG.370

BROMLEY, K.A., "BALL LIGHTNING", NATURE, 226,1970,PG.253

BROOK, M., G.ARMSTRONG, R.P.H.WINDER, B.VONNEGUT AND C.B.MOORE, "ARTIFICAL INITIATION OF LIGHTNING DISCHARGES", J.GEOPHYS.RES., 66,1961,PG.3967 (NBL)

BROOK, M., N.KITAGAWA AND E.J.WORKMAN, "QUANTITATIVE STUDY OF STROKES AND CONTINUING CURRENTS IN LIGHTNING DISCHARGES TO GROUND", J.GEOPHYS.RES., 67,1962, PG.649 (NBL)

BROOKS, C.F., "A CASE OF BALL LIGHTNING", AMER.METEOROL.SOC.BULL., 47,1946,PG.342

BROUGHTON, S., "BALL DISCHARGE IN THUNDERSTORMS", CHEM.NEWS, 27,1873a,PG.172 (*)

BROUGHTON, S., "BALL DISCHARGE IN THUNDERSTORMS", (SUMMARY), FORTSCHR.PHYS., 29, 1873b,PG.1003

BROUGHTON, S., "MANCHESTER, LITERARY AND PHILOSOPHICAL SOCIETY, COMMUNICATIONS", NATURE, 7,1873c,PG.415

BROUGHTON, S., "BALL DISCHARGE IN THUNDERSTORMS", PROC.MANCHESTER SOC., 4/3, 1873d (*)

BROVETTO, P., V.MAXIA AND G.BUSSETTI, "ON THE NATURE OF BALL LIGHTNING", J.ATMOS. TERR.PHYS., 38,1976,PG.921

BROWN, G.H., "BALL LIGHTNING", METEOROL.MAG., 86,1957,PG.375

BROWN, J., "UNAVAILABLE-TITLE UNKNOWN", LONDON TIMES, 1 DEC.1858 (*)

BROWN, S.C., "HIGH FREQUENCY GAS DISCHARGE BREAKDOWN", PROC.IRE, 39,1951,PG.1493

BROWNE, T., "ACCOUNT OF A THUNDERSTORM ON JUNE 28, 1665" IN "THE MISCELLANEOUS WRITINGS OF SIR THOMAS BROWNE", FARER AND FABER LTD., LONDON, 1964,PG.195

BRUCE, C.E.R., "BALL LIGHTNING, STELLAR ROTATION, AND RADIO GALAXIES", ENGINEER, 216,1963a,PG.1047

BRUCE, C.E.R., "BALL LIGHTNING", INST.ELECT.ENGR.J.(LONDON), 9,1963b,PG.357

BRUCE, C.E.R., "BALL LIGHTNING", NATURE, 202,1964,PG.996

BRUCE, C.E.R., "LIGHTNING", RESEARCH, 2,1967,PG.12

BRUCE, C.E.R. AND R.H.GOLDE, "THE LIGHTNING DISCHARGE", INST.ELECTR.ENGR.J. (LONDON), 88,II,1941,PG.487

BRUCE, H., "UNAVAILABLE-TITLE UNKNOWN", ELECTR.REV., 167,1960,PG.1070

BRUCHSAL, H., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 17,1900,PG.191

BRULEY-MOSLEY, M., "BOULE DE FEU", BULL.SOC.ASTRON.FR., 22,1908a,PG.528

BRULEY-MOSLEY, M., "METEOROLOGIE", L'ASTRONOMIE, 22,1908b,PG.528 (*)

BRZAK, W., "KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 48(3),1892a,PG.360

BRZAK, W., "KUGELBLITZ., METEOROL.ZEIT., 9,1892b,PG.355

BUCHWALDER, H., "UNAVAILABLE-TITLE UNKNOWN", NATURWISS., 1,1832,PG.327 (*)

BUCHWALDER, H., "UNAVAILABLE-TITLE UNKNOWN", LEHRBUCH METEOROL, 1891,PG.327

BUDDE, E., "SCHNELLBEWEGTE KUGELBLITZ", ZEIT.ANGEW.METEOROL., 37,1920,PG.87

BURCKHARDT, F., "EIN BLITZSTRAHL VON 14.JULI 1894", (SUMMARY), FORTSCHR.PHYS., 51(3),1895a,PG.400

BURCKHARDT, F., "EIN BLITZSTRAHL VON 14.JULI 1894", VERH.NATURF.GES.BASEL., 11, 1895b,PG.134 (*)

BURGER, K., "KUGELBLITZ UND BLITZFORSCHUNG", NATURWISS., 60,1973,PG.485

BURGESS, C.R., "METEOROLOGY FOR SEAMEN", BROWN, SON AND FERGUSON PUBLISHERS, GLASGON, 1950, PG.55

BUTTI, M., "FOUDRE GLOBULAIRE A MILAN, EN 1841 (JUIN?)", C.R.HEBD.SEANCES ACAD. SCI., 35,1852a,PG.193

BUTTI, M., "FOUDRE GLOBULAIRE A MILAN EN 1841", COSMOS, 1,1852b,PG.350 (*)

BUTZ, J.S., "GREAT BALLS OF FIRE", AIR FORCE MAG., APRIL 15,1968,PG.149

CABELLERO, E., "FOUDRE EN BOULE", CIEL ET TERRE, 11,1890a,PG.250

CABALLERO, E., "GLOBULAR LIGHTNING AT PONTEVEDRA", ELECTRICAL ENGINEER, 9,1890b, PG.187

CABALLERO, E., "GLOBULAR LIGHTNING", ELECTRICIAN, 24,1890c,PG.414

CABALLERO, E., "KUGELBLITZ IN PONTEVEDRA", ELEKTR.ZEIT., 11,1890d,PG.66 (*)

CABALLERO, E., "KUGELBLITZ IN PONTEVEDRA", (SUMMARY), FORTSCHR.PHYS., 46(3),1890e, PG.425

CABALLERO, E., "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 18,1890f,PG.167

CABALLERO, E., "FOUDRE EN BOULE", METEOROLOGIE, 38,1890g,PG.245

CABALLERO, E., "BALL LIGHTNING", METEOROL.MAG., 25,1890h,PG.99

CABALLERO, E., "KUGELBLITZ", METEOROL.ZEIT., 7,1890i,PG.158

CABALLERO, E., "BALL OF FIRE", NATURE, 41,1890j,PG.303

CABALLERO, E., "UNAVAILABLE-TITLE UNKNOWN", NATURWISS.RUND., 22,1890k,PG.284

CABALLERO, E., "KUGELBLITZ IN PONTEVEDRA", REV.INTERN.ELECT., 6,1890l,PG.202

CABALLERO, E., "KUGELBLITZ IN PONTEVEDRA", REV.SCI., 46,1890m,PG.286 (*)

CABANE, L., "UNAVAILABLE-TITLE UNKNOWN", L'ASTRONOMIE, 6,1887,PG.459

CADE, C.M., "THUNDERBOLTS AS THE X-WEAPON", DISCOVERY, 23,1962,PG.23

CADE, C.M., "RADIATION-THE NEW WEAPON", SCIENCE PROGRESS, 52,1964,PG.232

CADE, C.M. AND D.DAVIS, "TAMING OF THE THUNDERBOLTS", ABELARD-SCHUMAN LTD., NEW YORK, 1969

CADENAT, M., "UBER DIE KUGELBLITZ-ERSCHEINURGEN DES TORNADOS VON SAINT-CLAUDE", ZEIT.ANGEW.METEOROL., 7,1890,PG.285

CAILLEUX, M., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 46,1932,PG.569

CALLAHAN, P.S. AND R.W.MANKIN, "INSECTS AS UNIDENTIFIED FLYING OBJECTS", APPLIED OPTICS, 17(21),1978,PG.3355

CALLAHAN, P.S., "INSECTS AS UNIDENTIFIED FLYING OBJECTS: AUTHOR'S REPLY TO COMMENT; 1", APPLIED OPTICS, 18(16),1979,PG.2724

CALLAUD, A., "TRAIT DES PARATONNERRES", PARIS, 1874 (*)

CANCANI, M., "SOPRA UN CASO DI DUPLICE FULMINAZIONE AVVENUTO A CANTERANO IL 26. APRILE 1889 E SUL' ESISTENZA DEI FULMINI GLOBULARI", ATTI PONTIF.ACCAD.ROM.D. NUOVI LINCEI, 5,1889a,PG.796 (*)

CANCANI, M., "SOPRA UN CASO DI DUPLICE FULMINAZIONE AVVENUTO A CANTERANO IL 26. APRILE 1889 E SUL' ESISTENZA DEI FULMINI GLOBULARI", (SUMMARY), FORTSCHR.PHYS., 45(3),1889b,PG.514

CAPRON, J.R., "BALL LIGHTNING", METEOROL.MAG., 18,1883/84a,PG.41

CAPRON, J.R., "GLOBE LIGHTNING", METEOROL.MAG., 18,1883/84b,PG.57

CARLHEIM-GYLENSKOLD, V., "DES FOUDRES EN BOULE", BERICH.INTERNAT.METEOROL. DIREKTORENKONF INNSBRUCK, 1905a,APP.XXIII,PG.1 (*)

CARLHEIM-GYLENSKOLD, V., "UNAVAILABLE-TITLE UNKNOWN", KGL.ZEIT.METEOROL.GEODYN., SUPPL., 1905b,PG.113 (*)

CARPENTER, D.G., "PLASMA THEORY APPLIED TO BALL LIGHTNING", THESIS, IOWA STATE UNIVERSITY, 1962

CARPENTER, D.G., "BALL LIGHTNING AS A PLASMA PHENOMENON", AIAA STUDENT J., 1,1963, PG.25

CARRE, C., "UNAVAILABLE-TITLE UNKNOWN", LA LUMIERE ELECTRIQUE, 33,1889,PG.143

CARRUTHERS, J. AND B.D.P.FOSTER, "BALL LIGHTNING", METEOROL.MAG., 72,1947,PG.210

CARTWRIGHT, B.W., "LIGHTNING", LIFE MAG., 3,AUG.23,1938,PG.77

CARTWRIGHT, J., "UNAVAILABLE-TITLE UNKNOWN", J.SOC.TEL.ENGR., 1,1872,PG.372

CAWOOD, W. AND H.S.PATTERSON, "A CURIOUS PHENOMENON SHOWN BY HIGHLY CHARGED AEROSOLS", NATURE, 128,1931a,PG.637 (NBL)

CAWOOD, W. AND H.S.PATTERSON, "BALL LIGHTNING, OLD PUZZLE TO SCIENCE, MADE OUT OF SMOKE", SCIENCE NEWS LETT., 20,1931b,PG.366

CECCHINI, S., G.DIOCCO AND N.MANDOLESI, "POSITRON ANNIHILATION IN EAS AND BALL LIGHTNING", NATURE, 250,1974,PG.637

CECIL, H., "FIREBALL", NATURE, 30,1884,PG.289

CERRILLO, M., "SOBRE LAS POSIBLES INTERPRETACIONES ELECTROMAGNETICAS DEL FEMONENO DE LAS CENTELLAS", COMISION IMPLUSORA Y COORDINADORA DE LA INVESTIEACION CIENTIFICA, 1 ANUARIO,1943,PG.151, ENGLISH TRANSLATION, "CONCERNING THE POSSIBLE ELECTROMAGNETIC INTERPRETATION OF THE PHENOMENON OF LIGHTNING BALLS", UNPUBLISHED REPORT, RAYTHEON COMPANY, WAYLAND,MASS.,1960

CHALMERS, J.A., "ATMOSPHERIC ELECTRICITY", OXFORD AT THE CLARENDON PRESS, ENGLAND, 1949,PG.152

CHALMERS, J.A., "ATMOSPHERIC ELECTRICITY", PERGAMON PRESS, NEW YORK, 1957, PG.255

CHALMERS, J.A., "ATMOSPHERIC ELECTRICITY", PERGAMON PRESS, LONDON, 1976,PG.390

CHALMERS, L.E., "AN ACCOUNT OF AN EXTRAORDINARY FIREBALL BURSTING AT SEA", PHIL. TRANS.ROY.SOC.LONDON, 46,1751,PG.366

CHALMERS, L., "UNAVAILABLE-TITLE UNKNOWN", PHIL.TRANS.ROY.SOC.LOND., 10(2),1888, PG.481 (*)

CHAMEIDES, W.L., D.H.STEDMAN, R.R.DICKERSON, D.W.RUSH AND C.J.CICERONE, "NO- PRODUCTION IN LIGHTNING", J.ATMOS.SCI., 34,1977,PG.143 (NBL)

CHANDLER, M., "VIOLENT LIGHTNING STROKE IN SOUTH DEVON", METEOROL.MAG., 31,1896, PG.5

CHARLIER, L.A., "KUGELBLITZ-BEOBACHTUNG IN VORARLBERG", WETTER UND LEBEN, 18,1966, PG.204

CHARMAN, W.N., "PERCEPTUAL EFFECTS AND RELIABILITY OF BALL LIGHTNING REPORTS", J. ATMOS.TERR.PHYS., 33,1971a,PG.1973

CHARMAN, W.N., "AFTER IMAGES AND BALL LIGHTNING", NATURE, 230,1971b,PG.576

CHARMAN, W.N., "THE ENIGMA OF BALL LIGHTNING", NEW SCIENTIST, 56,1972,PG.632

CHARMAN, W.N., "BALL LIGHTNING PHOTOGRAPHED", NEW SCIENTIST, 69,1976,PG.444

CHARMAN, W.N., "BALL LIGHTNING", PHYS.REPORTS, 54(4),1979,PG.261

CHATTOCK, A.P., "GLOBULAR LIGHTNING DISCHARGE", NATURE, 109,1922,PG.106

CHATTOCK, H., "UNAVAILABLE-TITLE UNKNOWN", BRIT.ASSOC.ADV.SCI., 1898,PG.801

CHAUVEAU, B., "ELECTRICITE ATMOSPHERIQUE", PARIS, LIBRAIRIE OCTAVE DOIN, G.DOIN-ED., 1922

CHEETHAM, G.R., "ST. ELMO'S FIRE", MARINE OBSERVER, 26(172),1965,PG.81

CHILD, W., "ON THE EFFECTS OF LIGHTNING AT DORKIN IN SURREY", PHIL.TRANS.ROY.SOC. LOND., 49,1755,PG.309

CHIRVINSKIY, P.N., "MATERIALS ON OBSERVATIONS OF BALL LIGHTNING", KLIMAT I POGODA, 11,1936a,PG.5 (*)

CHIRVINSKIY, P.N., "MATERIALY PO NAVLYUDENIYAM NAO SHAROVYMI MOLNIYAI COVRANNYE V.K.CHERKASOM", KLIMAT I POGODA, NO.5,1936b,PG.49 (*)

CHIRVINSKIY, P.N., "UNAVAILABLE-TITLE UNKNOWN", KLIMAT I POGODA, NO.5,1936c,PG.68

CHIRVINSKIY, P.N., "K TEORII SHAROVYNH MOLNIY", METEOROLOGIYA I GIDROLOGIYA, NO.7,1936d,PG.78

CHIRVINSKIY, P.N., "SHAROV'LE MOLNII", PRIRODA, NO.6,1949,PG.14 (*)

CHIRVINSKIY, P.N., "PERVYE NABLYUDATELI SHAROVYKH MOLNII", PRIRODA, 43,NO.8,AUG., 1954,PG.116

CHOWN, J.B., W.E.SCHARFMAN, AND T.MARITA, "VOLTAGE BREAKDOWN CHARACTERISTICS OF MICROWAVE ANTENNAS", PROC.IRE, 47,1959,PG.1331

CLARE, P., "AN ACCOUNT OF SOME THUNDERSTORMS AND EXTRAORDINARY ELECTRICAL PHENOMENA THAT OCCURRED IN THE NEIGHBOURHOOD OF MANCHESTER ON TUESDAY THE 16TH OF JULY 1850", PHIL.MAG., 37,1850,PG.329

CLARK, L., "UNAVAILABLE-TITLE UNKNOWN", J.SOC.TEL.ENGR., 1,1872,PG.372

CLARK, R., "BALL LIGHTNING", WEATHER, 20,1965,PG.134

CLAUBRY, G.DE, "SUR LE TONNERRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 79,1874a, PG.137

CLAUBRY, G.DE, "SUR LE TONNERRE EN BOULE", (SUMMARY), FORTSCHR.PHYS., 30,1874b, PG.1177

CLAUBRY, G.DE, "SUR LE TONNERRE EN BOULE", INST.SCI.SOC.FR., 2,1874c,PG.241 (*)

CLAUBRY, G.DE, "SUR LE TONNERRE EN BOULE", MONDES, 34,1874d,PG.50(*)

CLAVEL, J., "COUP DE FOUDRE INTERESSANT", CIEL ET TERRE, 22,1901,PG.302

COCKING, A., "FIREBALL", NATURE, 30,1884,PG.269

COMANESTI, G., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 52,1938,PG.265

COOKE, B., "FIRE-BALL SEEN DEC 11, 1741", ROY.SOC.LOND.PHIL.TRANS., 42,1742/43, PG.25

CORLISS, W., "HANDBOOK OF UNUSUAL NATURAL PHENOMENA", SOURCEBOOK PROJECT, GLEN ARM, MD., 1977

CORONITI, S.C., "EVALUATION OF KAPITZA'S ARTICLE ON THE NATURE OF BALL LIGHTNING", UNPUBLISHED, REPORT RD-2-29-2-6, AVCO CORP., BOSTON,MASS., 1959

CORONITI-EDITOR, S.C., "PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY", INTERNATIONAL CONFERENCE PROCEEDINGS, MONTREUX, SWITZERLAND, 5-10 MAY 1963, ELSEVIER, AMSTERDAM

COURTRAI, R., "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 16,1860,PG.281

COVINGTON, A.E., "BALL LIGHTNING", NATURE, 226,1970,PG.252

COWAN, E.W., "GLOBULAR LIGHTNING", ELECTRICIAN, 22,1889,PG.720

CRAGGS, J.D., W.HOPWOOD AND J.M.MEEK, "ON THE LOCALIZED AFTERGLOWS OBSERVED WITH LONG SPARKS IN VARIOUS GASES", J.APPL.PHYS., 18,1947,PG.919

CRAIGE, H., "OBSERVATIONS OF LIGHTNING", SCIENCE, 72,1930,PG.344

CRAWFORD, W., "LIGHTNING-CHAIN FORMATION", NATURE, 53,1895,PG.5

CRAWFORD, J.F., "ANTIMATTER AND BALL LIGHTNING", NATURE, 239,1972,PG.395

CREW, E.W., "BALL LIGHTNING", NEW SCIENTIST, 56,1972,PG.764

CREW, E.W., "ATMOSPHERIC MYSTERIES AND LIGHTNING", ELECTR.REV., 199(24),1976a, PG.21 (NBL)

CREW, E.W., "FALL OF A LARGE ICE LUMP AFTER A VIOLENT STROKE OF LIGHTNING", J.METEOROL., 1(10),1976b,PG.312

CROOKS, W., "UNAVAILABLE-TITLE UNKNOWN", CHEM.NEWS, 65,1892,PG.301

CROSS, G.A., "METEOROLOGIE-UN CAS DE FOUDRE GLOBULAIRE", BULL.SOC.ASTRON.FR., 40, 1926,PG.504

CROSSLEY, A.W., "BALL LIGHTNING", NATURE, 114,1924,PG.10

CROTSENBURG, C.N., "BALL LIGHTNING", MON.WEATHER REV., 26,1898,PG.358

CULAFIC, M.R., "GROM I ZASTITA OD NJEG", IZDAVACKO PREDUZECE, GREDEVINSKA, KNJIGA, BEOGRAD, 1965,PG.76 (*)

CUNISSET-CARNOT, M., "LA FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 11,1897,PG.299

D'ABBADIE, A., "RAPPORT SUR UNE COMMUNICATION DE M. ANTOINE D'ABBADIE RELATIVE AUX ORAGES D'ETHIOPIE", C.R.HEBD.SEANCES ACAD.SCI., 34,1852,PG.894

DAERDAEEVSKII, B.L., "REDKII SNIMOK MOLNII", PRIRODA, NO.4,1957,PG.113

DAGUIN, L., "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 3 SEPT.1887

DALE, H.D., "BALL LIGHTNING", METEOROL.MAG., 58,1923,PG.258

DALLOZ, P., "UNAVAILABLE-TITLE UNKNOWN", LA MONTAGNE, 24,NO.210,1928,PG.81 (*)

DATLOV, J., "THE INVERTED ION MAGNETRON PRINCIPLE AND ITS USEFULNESS IN LABORATORY PLASMA PHYSICS AND COSMIC ELECTRODYNAMICS", CZECH.J.PHYS., B15,1965,PG.858

DAUVILLIER, A., "FOUDRE GLOBULAIRE ET REACTIONS THERMONUCLEAIRES", C.R.HEBD. SEANCES ACAD.SCI., 245,1957,PG.2155

DAUVILLIER, A., "SUR LA NATURE DE LA FOUDRE GLOBULAIRE", C.R.HEBD.SEANCES ACAD. SCI., 260,1965,PG.1707

DAUVILLIER, A., "SUR LE MECANISME DE LA FOUDRE GLOBULAIRE", REV.GEN.ELECT., 79, 1970,PG.433

DAVIDOV, B.V., "REDKAIA FOTOGRAFIIA SHAROVI MOLNII", PRIRODA, 47,NO.1,1958,PG.96

DAVIES, B., "BALL LIGHTNING PHENOMENA", NATURE, 115,1925,PG.640

DAVIES, P.C.W., "BALL LIGHTNING OR SPOTS BEFORE THE EYES?", NATURE, 230,1971, PG.576

DAVIES, P.C.W., "BALL LIGHTNING", NATURE, 260,1976,PG.573

DAVIES, D.W. AND R.B.STANDLER, "BALL LIGHTNING", NATURE, 240,1972,PG.144

DAWSON, G.A. AND R.C.JONES, "MODEL FOR BALL LIGHTNING", IN "PLANETARY ELECTRODYNAMICS", S.C.CORONITI AND J.HUGHES-ED., GORDON AND BREACH, NEW YORK, VOLUME 2,1968a,PG.193

DAWSON, G.A. AND R.C.JONES, "BALL LIGHTNING AS A RADIATION BUBBLE", FOURTH INTERNATIONAL CONFERENCE ON THE UNIVERSAL ASPECTS OF ATMOSPHERIC ELECTRICITY, TOKYO,JAPAN, MAY,1968b

DAWSON, G.A. AND R.C.JONES, "BALL LIGHTNING AS A RADIATION BUBBLE", PURE AND APPLIED GEOPHYSICS, 75,1969,PG.247

DECERFZ, C., "SUR UN CAS DE FOURDE QUI A FRAPPE LA PRISON DE LA CHATRE", C.R.HEBD. SEANCES ACAD.SCI., 25,1847,PG.85

DECHARME, C., "NOTES RELATIVES A UN ORAGE QUI A ECLAIR A AMIENS, LE 24 FEVRIER DERNIER", C.R.HEBD.SEANCES ACAD.SCI., 98.1884a,PG.606

DECHARME, C., "MEMOIRES PRESENTES-FOUDRE GLOBULAIRE", C.R.HEBD.SEANCES ACAD.SCI., 98,1884b,PG.658

DECHARME, C., "UNAVAILABLE-TITLE UNKNOWN", LA LUMIERE ELECTRIQUE, 11,1884c,PG.551

DECKER, F., "BEOBACHTUNG VON KUGELBLITZ", METEOROL.ZEIT., 38,1921,PG.183

DEMBER, H. AND U.MEYER, "KUGELBLITZ AM 12.MAI 1912 BEI DRESDEN", (SUMMARY), FORTSCHR.PHYS., 68(3),1912a,PG.310

DEMBER, H. AND U.MEYER, "KUGELBLITZ AM 12 MAI 1912 BEI DRESEND", METEOROL.ZEIT., 29,1912b,PG.384

DENNING, W.F., "METEORS AND ELECTRICAL PHENOMENON", METEOROL.MAG., 29,1894,PG.18

DERHAM, W., "OF THE METEOR CALLED IGNIS FATUUS, FROM OBSERVATIONS MADE IN ENGLAND" ROY.METEOROL.SOC.PHIL.TRANS., 26,1729,PG.204

DESSENS, J., "QUELQUES TORNADES FRANCAISES RECENTES", J.RECHERCHES ATMOSPHERIQUES, 2,1965,PG.91

DEWAN, E.M., "EYEWITNESS ACCOUNTS OF KUGELBLITZ", AIR FORCE CAMBRIDGE RESEARCH LAB PAPER, AFCRL-125, MARCH 1954

DEWAN, E.M., "ATTEMPTED EXPLANATIONS OF BALL LIGHTNING", AIR FORCE CAMBRIDGE RESEARCH LAB PAPER NO.67, AFCRL-64-927, NOV. 1964

DIBNER, B., "BENJAMIN FRANKLIN", IN "LIGHTNING", R.H.GOLDE-ED., ACADEMIC PRESS, NEW YORK, 1,1977,PG.47

DIJKHUIS, G.C., "THERMONUCLEAR ENERGY FROM BALL LIGHTNING", PROCEEDINGS OF THE INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE, 14TH, BOSTON, MA, AUGUST 5-10,1979,VOL.2,PG.1614

DIXON, F.E., "LIGHTNING", THE PETERBOROUGH CITIZEN, LONDON, 27 SEPT.1934

DIXON, F.E., "PHOTOGRAPHY AND BALL LIGHTNING", WEATHER, 10,1955,PG.98

DMITRIEV, M.T., "SHAROVAYA MOLNIIA VO VREMYA ZIMNEI GROZ'L", PRIRODA, NO.7,1956, PG.109

DMITRIEV, M.T., "CHEMICAL ANALYSIS OF BALL LIGHTNING", FOREIGN SCIENCE BULL., 3,NO.9,1967a,PG.30

DMITRIEV, M.T., "PRIRODA SHAROVOI MOLNII", PRIRODA, NO.6,1967b,PG.98

DMITRIEV, M.T., "STABILITY MECHANISM FOR BALL LIGHTNING", SOV.PHYS.-TECH.PHYS., 14(2),1969,PG.284, TRANSLATION OF ZH.TEKH.FIZ., 39(2),1969,PG.387

DMITRIEV, M.T., "NEW DATA ON BALL LIGHTNING", WISSENSCH.ZEIT.TECH.HOCHSCH.ILM., 16,1970,PG.87 (*)

DMITRIEV, M.T., "BALL LIGHTNING: NEW OBSERVATIONS AND NEW HYPOTHESES", NASA-TT- F-13,931, SEPT.,1971a

DMITRIEV, M.T., "SHAROVYYE MOLNII: NOVYYE NABLYUDENIYA I NOVYYE GIPOTEZY", PRIRODA, NO.6,1971b,PG.50

DMITRIEV, M.T., "NOVYYE PROBLEMYY SHAROVYI MOLNII", PRIRODA, NO.4,1973,PG.60

DMITRIEV, M.T., V.M.DERIUGIN AND G.A.KALINKEVICH, "OB OPTICHESKOM IZLUCHENII SHAROVOI MOLNII", ZH.TEKH.FIZ., 42,1972,PG.2187

DMITRIEV, M.T., V.M.DERYUGIN AND G.A.KALINKEVICH, "OPTICAL EMISSION FROM BALL LIGHTNING", SOV.PHYS.-TECH.PHYS., 17,NO.10,1973,PG.1724, TRANSLATION OF ZH. TEKHN.FIZ., 42,NO.10,1972,PG.2187

DMITRIEV, V.G., V.N.EMEL'YANOV, M.A.KASHINTSEV, V.V.KULIKOV, A.A.SOLOV'EV, M.F.STEL'MAKH AND O.B.CHEREDNICHENKO, "NONLINEAR PERCEPTION OF INFRARED RADIATION IN THE 800-1355 NM RANGE WITH HUMAN EYE", SOV.J.QUANTUM ELECTRON., 9(4),1979,PG.475

DOBELMANN, V., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 25,1911,PG.262

DOBSON, H.J.E., "BALL LIGHTNING AT NORWOOD", METEOROL.ZEIT., 60,1925,PG.162

DOLBEAR, A.E., "GLOBULAR LIGHTNING", NATURE, 11,1887,PG.38

DOLBEAR, A.E., "GLOBULAR LIGHTNING", SCIENCE, 11,1888,PG.38

DOLEZALEK, H., "EINIGE KUGELBLITZ-BEOBACHTUNGEN", GEOPHYS.PURE APPL.(MILAN), 20, 1951,PG.183

DOLEZALEK, H., "COMMENT ON 'ON THE PROBLEM OF BALL LIGHTNING' BY W.I.ARABADJI", J.GEOPHYS.RES., 82(24),1977,PG.3498

DOLGOPOLOV, N., "BUDUSHCHEYE SHAROVOI MOLNII", ZNANIYE-SILA, NO.3,1957,PG.17 (*)

DOUBLET, J.M.G., "UNAVAILABLE-TITLE UNKNOWN", L'ECLAIRAGE ELECTRIQUE, 20,1899a, PG.393

DOUBLET, J.M.G., "UNAVAILABLE-TITLE UNKNOWN", L'ECLAIRAGE ELECTRIQUE, 21,1899b, PG.142

DUCROS, M.H., "FOUDRE; ORAGES", BULL.SOC.ASTRON.FR., 18,1904,PG.476

DUDLEY, L.P., "LIGHTNING AND KINDRED PHENOMENA", ELECTRICIAN, 129,1942,PG.507

DUFAY, J. AND T.MAO-LIN, "SPECTRA OF LIGHTNING", ANN.GEOPHYS., 5(2),1949,PG.137

DUMAS, M., "UNAVAILABLE-TITLE UNKNOWN", BULL.SOC.ENCOURAGEMENT, 13,1866,PG.153

DUNN, M., "LES NOUVEAUTES PHOTOGRAPHIQUES", LIBRAIRE ILLUSTRE, PARIS, 1894, PG.253-259 (*)

DYCK, C.VAN, "GLOBULAR LIGHTNING", NATURE, 11,1887,PG.110

DYCK, C.VAN, "GLOBULAR LIGHTNING", SCIENCE, 11,1888,PG.110

EATON, H.S., "NOTE ON A DISPLAY OF GLOBULAR LIGHTNING AT RINGSTEAD BAY, DORSET, ON AUGUST 17, 1876", ELECTRICIAN, 19,1887a,PG.179

EATON, H.S., "NOTE ON A DISPLAY OF GLOBULAR LIGHTNING AT RINGSTEAD BAY, DORSET, ON AUGUST 17TH, 1876", METEOROL.MAG., 22,1887b,PG.87

EATON, H.S., "NOTE ON A DISPLAY OF GLOBULAR LIGHTNING AT RINGSTEAD BAY, DORSET, ON AUGUST 17TH, 1876", AMER.J.METEOROL., 4,1888,PG.148

ECKARDT, B., "MERKWURDIGE BLITZFORM", METEOROL.ZEIT., 31,1914,PG.548

EDLUND, M., "UNAVAILABLE-TITLE UNKNOWN", OFVER.KONGL.VET.AKAD.FORH., 40,1883,PG.86

EKVAL, H.N., "COUGNARD DEIONIZERS: NEW MYSTERY IN LIGHTNING PROTECTION", ELECTRICAL WORLD, 147,PT.2,11 MARCH,1957,PG.11

ELECCION, M., "BALL LIGHTNING", IEEE TRANS.AERO.ELECT.SYS., 6,1970,PG.83

ELIOT, L., "ACCOUNT OF THE EFFECTS OF LIGHTNING AT STEEPLE ASHTON AND HOLT, IN THE COUNTY OF WILTS, ON THE 20TH OF JUNE, 1772", ROY.SOC.LOND.PHIL.TRANS., 68.1773, PG.231

ELISEEV, A.A., "M.V.LOMONOSOV", LENINGRADSCOE OTDELENIE, LENINGRAD, 1941

ELLIOT, G., "BALL LIGHTNING", METEOROL.MAG., 39,1904,PG.133

ENDEAN, V.G., "BALL LIGHTNING AS ELECTROMAGNETIC RADIATION", NATURE, 263,1976, PG.753

ENDEAN, V.G., "BALL LIGHTNING", 5TH INTERNATIONAL CONFERENCE ON GAS DISCHARGES, LIVERPOOL, ENGLAND, 11-14 SEPT.,1978,PG.116

EPINAL, M., "UNAVAILABLE-TITLE UNKNOWN", ANN.CHEM.PHYS., 19,1821,PG.86 (*)

EPSTEIN, H., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.PHYSIK, 71,1911,PG.28

ERIKSSON, A.J., "VIDEO-TAPE RECORDING OF A POSSIBLE BALL LIGHTNING EVENT", NATURE, 268,1977a,PG.35

ERIKSSON, A.J., "AN UNUSUAL LIGHTNING FLASH", WEATHER, 32,1977b,PG.102

ERRERA, L. AND A.UECLE, "UN CAS INTERESSANT D'ECLAIR EN BOULE", L'ASTRONOMIE, 18, 1904,PG.99 (*)

ESNAULT, G., "ETUDE DU COUP DE FOUDRE GLOBULARE DU 29 AVRIL 1930 SUR LA FERME DE L'ECHELLERIE COMMUNE DE WIEIL-BAUGE PRES BAUGE (MAINE-ET-LOIRE)", LA METEOROLOGIE, 10,1934,PG.552 (*)

ESPEE, M.DE, "CORRESPONDANCE", C.R.HEBD.SEANCES ACAD.SCI., 35,1852,PG.400

ESPERT, M., "TONNERRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 35,1852,PG.192

ETTE, A.I.I., "LABORATORY STUDIES OF POINT-DISCHARGE FROM MULTIPLE POINTS IN IRREGULAR CONFIGURATION", J.ATMOS.TERR.PHYS., 38,1966,PG.982 (NBL)

EVENSON, K.M., "BALL LIGHTNING RESEARCH AT HIGHLAND LOOKOUT, MOUNTAIN", DOUGLAS MISSILE AND SPACE SYSTEMS DIVISION PAPER,DAC-60941, 51-1-R8, JAN. 1968

EVERSHED, S., "GLOBULAR LIGHTNING", ELECTRICIAN, 22,1889,PG.443

EVRARD, F., "NOTE SUR LES OBSERVATIONS DES COUPS DE FOUDRE EN BELGIQUE", MOUVEMENT INDUSTRIEL BELGE, 3,1885,PG.21 (*)

EVRARD, F., "COUPS DE FOUDRE EN BELGIQUE PENDANT L'ANNEE 1887", CIEL ET TERRE, 10, 1889/90,PG.270

EVRARD, F. AND L.LAMBOTTE, "CINQUIEME NOTE SUR LES OBSERVATIONS DES COUPS DE FOUDRE EN BELGIQUE", BULL.SOC.BELGE ELECTR., 6,1889,PG.34 (*)

EVRARD, F. AND L.LAMBOTTE, "SUR LES OBSERVATIONS DES COUPS DE FOUDRE EN BELGIQUE", (SUMMARY), FORTSCHR.PHYS., 47(3),1891a,PG.355

EVRARD, F. AND L.LAMBOTTE, "SUR LES OBSERVATIONS DES COUPS DE FOUDRE EN BELGIQUE", LA LUMIERE ELECTRIQUE, 41,1891b,PG.192 (*)

EVRAND, F. AND L.LAMBOTTE, "SUR LES OBSERVATIONS DES COUPS DE FOUDRE EN BELGIQUE", ZEIT.ANGEW.METEOROL., 8,1891c,PG.319 (*)

FAHRIG, E., "GLOBULAR LIGHTNING", METEOROL.MAG., 24,1889,PG.10

FAHRIG, E., "GLOBULAR LIGHTNING", ELECTRICIAN, 22,1890,PG.413

FALKNER, M.F., "AN OCCURRENCE OF BALL LIGHTNING", METEOROL.MAG., 93,1964,PG.95

FARADAY, M., "EXPERIMENTAL RESEARCHES IN ELECTRICITY", ROY.SOC.LOND.PHIL.TRANS., 123,1833,PG.23

FARADAY, M., "EXPERIMENTAL RESEARCHES IN ELECTRICITY", B.QUARITCH, LONDON, 1,1839, PG.523

FAY, M.H., "GLOBULAR LIGHTNING", ELECTRICIAN, 26,1890,PG.5

FAYE, H., "UNAVAILABLE-TITLE UNKNOWN", ANNUAIRE AU ROI PAR LE BUREAU DES LONGITUDES, 1877,PG.483

FAYE, H., "SUR LES BOULES DE FEU OU GLOBES ELECTRIQUES DU TORNADO DE SAINT-CLAUDE, D'APRES LE RAPPORT DE M.CADANET", C.R.HEBD.SEANCES ACAD.SCI., 111,1890a,PG.492

FAYE, H., "SUR LES BOULES DE FEU OU GLOBES ELECTRIQUES DU TORNADO DE SAINT- CLAUDE", (SUMMARY), FORTSCHR.PHYS., 46(3),1890b,PG.424

FAYE, H., "UNAVAILABLE-TITLE UNKNOWN", L'ASTRONOMIE, 10,1891a,PG.22

FAYE, H., "UNAVAILABLE-TITLE UNKNOWN", GAEA, 27,1891b,PG.185

FEHR, U., "BALL OF FIRE, A LABORATORY ILLUMINATED CLOUD PHENOMENON", MASTERS THESIS, HEBREW UNIVERSITY, JERUSALEM, ISRAEL, 1963

FELSHER, M., "BALL LIGHTNING", NATURE, 227,1970,PG.982

FERGUSON, R.M., "ELECTRICITY", LONDON AND EDINBURGH J., 1866,PG.97 (*)

FERRAN, A., "FOUDRE EN BOULE", LE COSMOS, OCT.,1896a,PG.354 (*)

FERRAN, A., "FOUDRE EN BOULE", METEOROLOGIE, 44,1896b,PG.236

FESSENDEN, R.A., "NATURE OF THE LIGHTNING DISCHARGE", ELECTRICAL WORLD AND ENGINEER, 35,1899,PG.551

FIEUX, R. AND P.HUBERT, "TRIGGERED LIGHTNING HAZARDS", NATURE, 260,1976, PG.188 (NBL)

FIEUX, R., G.GARY, AND P.HUBERT, "ARTIFICIALLY TRIGGERED LIGHTNING ABOVE LAND", NATURE, 257,1975,PG.212

FIGUIER, L., "LES GRANDES INVENTIONS", PARIS, 1870 (*)

FIGUIER, L., "MERAVIGLIE E CONQUISTE DELLE SCIENZA L'ELETTRICITA E LE SUE APPLICAZIONI", VOLUME PRIMO, MILAN, 1884 (*)

FINDEISEN, W., "UBER DIE ENTSTEHUNG DER GEWITTER ELEKTRIZITAT", METEOROL.ZEIT., 57,1940,PG.201 (NBL)

FINKELSTEIN, D., "RESEARCH DIRECTED TOWARD UNDERSTANDING BEHAVIOR AND DETECTION OF PLASMAS IN MAGNETIC FIELDS", AFCRL-68-0210, 1968

FINKELSTEIN, D. AND J.RUBINSTEIN, "BALL LIGHTNING", PHYS.REV., 135,1964,PG.A390

FITZGERALD, M., "NOTES ON THE OCCURRENCE OF GLOBULAR LIGHTNING AND WATERSPOUTS IN CO. DONEGAL, IRELAND", ROY.METEOROL.SOC.Q.J., 4,1878,PG.160

FLAMMARION, C., "THE ATMOSPHERE", J.GLAISHER-ED., HARPER AND BROTHERS, NEW YORK, 1874,PG.426 AND 440

FLAMMARION, C., "LES VICTIMES DE LA FOUDRE ET SES CAPRICES", BULL.SOC.ASTRON.FR., 13,1899,PG.145

FLAMMARION, C., "LES VICTIMES DE LA FOUDRE ET SES CAPRICES", BULL.SOC.ASTRON.FR., 18,1904a,PG.153

FLAMMARION, C., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 18,1904b,PG.378

FLAMMARION, C., "LES CAPRICES DE LA FOUDRE", BULL.SOC.ASTRON.FR., 18,1904c,PG.421

FLAMMARION, C., "LES MYSTERES DE LA FOUDRE", BULL.SOC.ASTRON.FR., 22,1908,PG.440

FLAMMARION, C., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 25,1911,PG.262

FLAMMARION, C., "LES PHENOMENES DE LA FOUDRE", PARIS, 1927,PG.117 (*)

FLEMING, S.J. AND M.J.AITKEN, "RADIATION DOSAGE ASSOCIATED WITH BALL LIGHTNING", NATURE, 252,1975,PG.220

FLINT, H.T., "BALL LIGHTNING", ROY.METEOROL.SOC.Q.J., 65,1939a,PG.532

FLINT, H.T., "A NOTE ON A THEORY PROPOSED BY TH. NEUGEBAUER", ROY.METEOROL.SOC.Q. J., 65,1939b,PG.532

FLOYD, F.G., "GLOBULAR LIGHTNING", ENGLISH MECH., 45,1887,PG.159

FONTENAY, G.DE, "COUPS DE FOUDRE", BULL.SOC.ASTRON.FR., 15,1901,PG.303

FONTVIELLE, W.DE, "ECLAIRS ET TONNERE", HACHETTE ET CIE, PARIS, 1867,PG.51&67 (*)

FONTVIELLE, W.DE, "THUNDER AND LIGHTNING", SAMPSON,LOW,SON AND MARSTON, LONDON, 1868,PG.32 (*)

FORSTER, T., "RESEARCHES ABOUT ATMOSPHERIC PHAENOMENA", HARDING, MAVOR AND LEPARD, LONDON, 1823,PG.214

FOSTER, B.D.P., "BALL LIGHTNING", METEOROL.MAG., 72,1947,PG.210

FOUCHET, J., "LE MECANISME COMPLEXE DE L'ECLAIR ET LE MYSTERE DE LA FOUDRE EN BOULE", LA NATURE, 92,NO.3347,1964,PG.81 (*)

FOUGERES, G., "DICTIONNAIRE DES ANTIQUITES GRECQUES ET ROMAINES", CH.DAREMBERG ET EDM.SAGLIO, PARIS, PG.1896 (*)

FRANCOIS, H., "METEOROLOGIE-CURIEUX COUP DE FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 25,1911,PG.333

FRANK-KAMENETSKIY, D.A., "PLAZMA-CHETVERTOYE SOSTOYANIYA VESHCHESTVA", MOSCOW, 1963 (*)

FRANKLIN, B., "A LETTER OF BENJAMIN FRANKLIN, ESQ. TO MR. P.COLLINSON, F.R.S., CONCERNING AN ELECTRICAL KITE", ROY.SOC.LOND.PHIL.TRANS., 47,1752,PG.565 (NBL)

FREIER, G.D., "THE ELECTRIC FIELD OF A LARGE DUST DEVIL", J.GEOPHYS.RES., 65,1960, PG.3504 (NBL)

FREIHERR, J.A., "KUGELBLITZ IN CARLSKRONA", METEOROL.ZEIT., 13,1896,PG.476 PG.476

FREMHOLT, G., "EIN KUGELBLITZ IN DANEMARK", (SUMMARY), FORTSCHR.PHYS., 33,1877a, PG.1289

FREMHOLT, G., "EIN KUGELBLITZ IN DANEMARK", GAEA, 13,1877b,PG.565 (*)

FRENKEL', Y.I., "O PRIRODA SHAROVOI MONLII", ZH.EKSP.TEOR.FIZ., 10,1940,PG.1424

FRENKEL', Y.I., "TEORIYA YAVLENIY ATMOSFERNOGO ELEKTRICHESTVA", MOSCOW-LENINGRAD, GITTL, 1949 (*)

FRIEDRICH, W., "ELMSFEUERBEOBACHTUNG AUF DEM KAHLEN-ASTEN", METEOROL.ZEIT., 43, 1926,PG.229 (NBL)

FRIESENHOF, G., "EIN MERKWURDIGER BLITZ", METEOROL.ZEIT., 27,1910,PG.560

FRITSCH, V., "DER NACHWEIS UND DIE GEOELEKTRISCHE UNTERSUCHUNG EINES BLITZNESTES", GERLANDS BEITRAGE ZUR GEOPHYSIK, 71,1962,PG.300 (NBL)

FROMHOLT, H., "UNAVAILABLE-TITLE UNKNOWN", KOLN.ZEIT., 17 APR.1884

FRY, E., "A REMARKABLE LIGHTNING DISCHARGE", NATURE, 74,1906,PG.198

FUESS, P., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 48,1931,PG.255

FUNDER, L., "ERMITTLUNG, URSACHEN UND BEDEUTUNG DES IONENGEHALTES DER GRUBEN WETTER", BEITR.ZUR GEOPHYS., 54,1939,PG.370

GABRAKOV, S., "KULBOVIDNATA MULNIIA", KHID.METEOROL., 15,1966,PG.59 (*)

GAILLARD, D., "PHENOMENES ELECTRIQUES DANS LA REGION DU TCHAD", BULL.SOC.ASTRON. FR., 26,1912,PG.436

GALLI, I., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 7,1890,PG.238

GALLI, I., "UNAVAILABLE-TITLE UNKNOWN", MEM.R.ACCAD.SCI.IST.BOLOGNA, 1,1891,PG.315

GALLI, I., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 19,1902,PG.239

GALLI, I., "COMMUNICAZIONE RELATIVA AI PARAFULMINI ED AI FULMINI ASCENDENTI E GLOBULARI", ATTI.PONTIF.ACCAD.ROM.D.NUOVI LINCEI, 1907 (*)

GALLI, I., "DELLA PROTEZIONE OFFERA DAI PARAFULMINI EDI ALCUNI QUESITI SULLA NATURA DEL FULMINE", MEM.PONTIF.ACCAD.ROM.D.NUOVE LINCEI, 1908,PG.36 (*)

GALLI, I., "DI UN RECENTE FULMINE A ROCCAGORGA E DI ALTRI CASI EGUALMENTE NOTEVOLI", ATTI PONTIF.ACCAD.ROM.D.NUOVE LINCEI, 1909a (*)

GALLI, I., "DI ALCUNI FULMINI RECENTI E ANTICHI NEL LAZIO E ROMA", ATTI PONTIF. ACCAD.ROM.D.NUOVI LINCEI, 1909b (*)

GALLI, I., "NOTIZIE DI ALCUNI FULMINI", ATTI PONTIF.ACCAD.ROM.D.NUOVI LINCEI, 1910a (*)

GALLI, I., "DI UNA RECENTE FULMINAZIONE A CORI, CON APPENDICA DI OSSERVAZIONI SUR LAMPI", ATTI PONTIF.ACCAD.ROM.D.NUOVI LINCEI, 1910b (*)

GALLI, I., "I PRINCIPALI CARATTERI DEI FULMINI GLOBULARI", MEM.PONTIF.ACCAD.ROM.D. NUOVI LINCEI, 28,1910c,PG.54 (*)

GALLI, I., "RACCOLTA E CLASSIFIEAZIONE DI FENOMENI LUMINOSI OSSERVATI NEI TERREMOTI", BOLL.SOC.SISMOL.ITAL., 14,1910d,PG.69 (*)

GALLI, I., "RACCOLTA E CLASSIFICAZIONE DI FENOMENI LUMINOSI ASSERVATI NEI TERROMOTI", BOLL.D.SOC.SIS.ITAL., 14,1910e,PG.221 (*)

GALLI, I., "I PRINCIPALI CARATTERI DEI FULMINI GLOBULARI", CIEL ET TERRE, 32, 1911a,PG.238

GALLI, I., "GLI EFFETTI MECCANICI DEI FULMINI GLOBULA I", MEM.PONTIF.ACCAD.ROM.D. NUOVI LINCEI, 29,1911b,PG.9 (*)

GALLI, I., "EIN ZYLINDERBLITZ", REV.NEPHOLOG., 6,1911c,PG.538 (*)

GALLI, I., "EIN ZYLINDERBLITZ", ZEIT.ANGEW.METEOROL., 28,1911d,PG.161 (*)

GALLI, I., "GLI EFFETTI FISICI E CHIM CI DEI FULMINI GLOBULARI", MEM.PONTIF.ACCAD. ROM.D.NUOVI LINCEI, 30,1912,PG.17 (*)

GALLI, I., "ALTRI FULMINI GLOBULARI INEDITI", ATTI PONTIF.ACCAD.ROM.D.NUOVI LINCEI, 66,1913a,PG.11 (*)

GALLI, I., "EFFETTI DEI FULMINI GLOBULARI SUGLI ALBERI E SULLE ERBE", MEM.PONTIF. ACCAD.ROM.D.NUOVI LINCEI, 31,1913b,PG.225 (*)

GALLI, I., "ALTRI FULMINI GLOBULARI INEDITI", (SUMMARY), FORTSCHR.PHYS., 69(3), 1913c,PG.320

GALLI, I., "FULMINI GLOBULARI NEL 1914", ATTI PONTIF.ACCAD.ROM.D.NUOVI LINCEI, 68,1914,PG.177 (*)

GALLI, I., "FULMINI GLOBULARI NELL' ANNO 1915", ATTI PONTIF.ACCAD.ROM.D.NUOVI LINCEI, 69,1915a,PG.59 (*)

GALLI, I., "EFFETTI DEI FULMINI GLOBULARI SUGLI ALBERI E SULLE ERBE", (SUMMARY), FORTSCHR.PHYS., 71(3),1915b,PG.255

GALLI, I., "OSSERVAZIONI INEDITE O QUASI SCONOSCUITE DI FULMUNI GLOBULARI E DI EFFETTI RARI", ATTI PONTIF.ACCAD.ROM.D.NUOVI LINCEI, 16 MARCH 1916a (*)

GALLI, I., "FULMINI GLOBULARI NEL 1914", (SUMMARY), FORTSCHR.PHYS., 72,1916b, PG.274

GALLI, I., "FULMINI GLOBULARI NELL' ANNO 1915", (SUMMARY), FORTSCHR.PHYS., 73(3), 1917,PG.136

GALLI, I., "OSSERVAZIONI ITALIANE DI FULMINE GLOBULARE DI LAMPI RARI NEL 1917 E 1918: NOTA XXI", ATTI PONTIF.ACCAD.ROM.D.NUOVI LINCEI, 15 JUNE 1919 (*)

GALLI, I., "LA FOUDRE GLOBULAIRE", CIEL ET TERRE, 36,1920a,PG.73

GALLI, I., "OSSERVAZIONI INEDITE O QUASI SCONOSCUITE DI FULMUNI GLOBULARI E DI EFFETTI RARI", CIEL ET TERRE, 36,1920b,PG.76

GALLI, I., "LA FOUDRE GLOBULAIRE ET LES TRAVAUX", CIEL ET TERRE, 36,1920c,PG.140

GALLOP, J.W., T.L.DUTT AND H.GIBSON, "FORCES ON CHARGED PARTICLES OF A PLASMA IN A CAVITY", NATURE, 188,1960,PG.397

GALTON, E.M.G., "BALL LIGHTNING", THE TIMES (LONDON), NO.58, MAY 17,1971,PG.13 (*)

GARFIELD, E., "WHEN CITATION ANALYSIS STRIKES BALL LIGHTNING", CURRENT COMMENTS, NO.20,1976,PG.5

GARREAU, R., "ACADEMIE DES SCIENCES - COUP DE FOUDRE VIOLENT", BULL.SOC.ASTRON. FR., 53,1939a,PG.424

GARREAU, R., "OBSERVATION D'EN COUP DE FOUDRE EN BOULE", C.R.HEBD.SEANCES ACAD. SCI., 209,1939b,PG.60

GATHEMANN, H., "EIGENARTIGER BLITZSCHLAG", ANN.HYDRO.MARIT.METEOROL., 17,1889, PG.39

GATHEMANN, H., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 6,1889,PG.90

GAVACHE, M.R., "FOUDRE GLOBULAIRE?", BULL.SOC.ASTRON.FR., 65,1951,PG.474

GEDDES, A.E.M., "METEOROLOGY", BLACKIE AND SON, LONDON, 2ND ED., 1939

GEERK, J. AND H.KLEINWACHTER, "GASENTLADUNG IN BRENNPUNKT EINES RADAR PARABOLOIDS", ZEIT.PHYS., 159,1960,PG.378 (NBL)

GEIST, F., "EINE KUGELBLITZBEOBACHTUNG IN OBERBAYERN", UMSCHAU, 19,1949,PG.255

GELLER, R. AND M.LUCARAIN, "OSCILLATIONS IONIQUES STATIONNAIRES DANS LES PLASMOIDES DE HAUT FREQUENCE EN ABSENCE DE CHAMP MAGNETIQUE", C.R.HEBD.SEANCES ACAD.SCI., 253,1961,PG.1542 (NBL)

GENZ, H., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ERD.UNTER., 4,1952,PG.186

GERASIMENKO, T.F., "SHAROVAIA MOLNIIA VO VREMIA ZIMMEI GROZY", PRIRODA, NO.7,1956, PG.109

GERHARZ, R., "COFFERS RE-OPENED", OPTICAL SPECTRA, 13(17),1979,PG.13

GERLACH, W., "UBER DIE BEOBACHTUNG EINES KUGELBLITZES", NATURWISS., 15,1927,PG.522

GERSTEN, A., "PLASMA BALL OF FIRE", THESIS, HEBREW UNIVERSITY OF ISRAEL, 1963

GERVAIS, M.R.V., "METEOROLOGIE - LA FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 48, 1934,PG.277

GEZEKHUS, N.A., "SHAROVIDNYYE I PLAMENOOBRAZNYYE MOLNII KAK OSOBYYE TIPY RAZRYADOV ATMOSFERNOGO ELEKTRICHESTVA", ST. PETERSBURG, 1899 (*)

GEZEKHUS, N.A., "ELEKTRICHESKOYE PLAMYA I SHAROVIDNAYA MOLNIYA", ZH.FIZ.KHIM. OBSH., 32,1900a,PG.127

GEZEKHUS, N.A., "O SHAROVOY MOLNII", ST. PETERSBURG, 1900b (*)

GIBBS-SMITH, C.H., "ON FIREBALLS", NATURE, 232,1971,PG.187

GILBERT, O., "DIE METEOROLOGISCHEN THEORIEN DES GRIECHISCHEN ALTERTUMS", LEIPZIG, 1907,PG.619 (*)

GILMORE, G., "GLOBULAR LIGHTNING", NATURE, 103,1919,PG.284

GLADKOV, K., "ZAGADKA SHAROVOI MOLNII", TEKHNIKA-MOLODEZHI, 26,1958,PG.28 (*)

GOBEL, P., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 6,1889a,PG.68

GOBEL, P., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 6,1889b,PG.237

GOCKEL, A., "DAS GEWITTER", GORRES-GESELLSCHAFT, BONN, 1895 (*)

GOCKEL, A., "UBER KUGELBLITZ", METEOROL.ZEIT., 26,1909,PG.458

GOCKEL, A., "DAS GEWITTER", (SUMMARY), FORTSCHR.PHYS., 61(3),1905a,PG.318

GOCKEL, A., "DAS GEWITTER", NATURWISS.RUND., 20,1905b,PG.447 (*)

GODERUS, A., "FOUDRE EN BOULE", IN ANON, "LES ORAGES", CIEL ET TERRE, 9,1889/90, PG.193

GODLONTON, R., "A REMARKABLE DISCHARGE OF LIGHTNING", NATURE, 53,1896,PG.273

GODWIN-AUSTIN, W.H., "LIGHTNING PHENOMENON", NATURE, 28,1883,PG.173

GOLD, E., "THUNDERBOLTS: THE ELECTRIC PHENOMENON OF THUNDERSTORMS", NATURE, 169, 1952,PG.561

GOLDE, R.H., "THUNDERSTORMS", INST.ELECTR.ENGR.J., 8,1962,PG.242

GOLDE, R.H., "THE LIGHTNING CONDUCTOR", J.FRANKLIN INSTITUTE, 283,1967,PG.451(NBL)

GOLKA, R.K. AND R.W.BASS, "TESLA'S BALL LIGHTNING THEORY, A BGK-WAVE SOLUTION-PAIR LANGMUIR-DEBYE SHEATH SURFACE-TENSION HYPOTHESIS, THE FARNSWORTH EFFECT, AND THE "HYDROTRON" ELECTROSTATIC-INTERNAL SELF-CONTAINED PLASMOID CONCEPT", ANNUAL CONTROLLED FUSION THEORY CONFERENCE, PAPER J3, SAN DIEGO, CA, MAY 4-6,1977

GOODLET, G.L., "LIGHTNING", INST.ELECTR.ENGR.J., 81,1937,PG.1

GORDON, W., "ACCOUNT OF A FIREBALL SEEN DEC 11, 1741", ROY.SOC.LOND.PHIL.TRANS., 42,1742/43,PG.58

GOUW, M.J.E.TER, "BOULE DE FEU", BULL.SOC.ASTRON.FR., 21,1907,PG.313

GPOSU, S., "UNAVAILABLE-TITLE UNKNOWN", ELECTROTEHNICA, 8(2),1960,PG.57

GRAF-PFEIL, L., "DER URSPRUNG DER METEORITEN", GAEA, 22,1886a,PG.229 (*)

GRAF-PFEIL, L., "DIE HIRSCHBERGER KUGELBLITZE", GAEA, 22,1886b,PG.474 (R)

GRAY, D.E., "AMERICAN INSTITUTE OF PHYSICS HANDBOOK", COORDINATING EDITOR, MCGRAW- HILL, NEW YORK, 1957,PG.2-125 (NBL)

GREAVES, C., "DISCUSSIONS ON WATERSPOUTS AND GLOBULAR LIGHTNING", ROY.METEOROL. SOC.Q.J., 4,1878,PG.165

GREFEN, H., "UNAVAILABLE-TITLE UNKNOWN", SCHR.NAT.VER.SCH.HOLST., 6,1884,PG.613

GROBE, G., "WIEDER EIN KUGELBLITZ AUF DEM BROCKEN", METEOROL.ZEIT., 44,1927a, PG.312

GROBE, G., "EINE KUGELBLITZARTIGE ERSCHEINUNG", METEOROL.ZEIT., 44,1927b,PG.391

GRONEMANN, J., "TWEE MERKWAARDIGE BLIKSEMS", (SUMMARY), FORTSCHR.PHYS., 52(3), 1896a,PG.301

GRONEMANN, J., "TWEE MERKWAARDIGE BLIKSEMS", NAT.TIJDSCHR.NED.INDIE, 3,1896b, PG.269 (*)

GROSSMANN, D., "FEUERKUGELN", (SUMMARY), FORTSCHR.PHYS., 5,1849,PG.455

GRUNSKY, C.E., "ELECTRIC STORM IN SOUTHERN CALIFORNIA", MON.WEATHER REV., 35,1907, PG.228

GUBICHEV, V.A., "POSSIBLE MECHANISM OF BALL LIGHTNING FORMATION", UL'YANOVSKIY GOSUDORSTVENNYY PEDAGOGICHESKIY INSTITUT IMENI I.N. UL'YANOVA, UCHENYYE ZAPISKI, SERIYA TEKHNICHESKAYA, 20(4),1966,PG.203

GUBICHEV, V.A., "A NEW THEORY OF BALL LIGHTNING", FOREIGN SCIENCE BULL., 4(6), 1968,PG.27

GUCINSKI, H., "OBSERVATION OF BALL LIGHTNING", WEATHERWISE, 31(4),1978,PG.167

GUILLEMIN, A., "UNAVAILABLE-TITLE UNKNOWN", LE MONDE PHYSIQUE, 3,1883,PG.492

GUILLON, M., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 62,1948,PG.323

GUNTHER, S., "UNAVAILABLE-TITLE UNKNOWN", GEOPHYSIK, STUTTGART, 1897 (*)

GUREVICH, A.V. AND L.P.PITAEVSKII, "RECOMBINATION COEFFICIENT IN A DENSE LOW- TEMPERATURE PLASMA", SOV.PHYS.JETP, 19(4),1964,PG.870, TRANSLATION OF ZH.EKSP. TEOR.FIZ.SSSR, 46,1964,PG.1281

HAAG, D., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 31,1914,PG.240

HAGENAU, M., "RATHSELHAFTE BLITZERSCHEINUNGEN", GARTENLAUBE, 24,1896a,PG.395 (*)

HAGENAU, M., "RATHSELHAFTE BLITZERSCHEINUNGEN", (SUMMARY), FORTSCHR.PHYS., 52(3), 1896b,PG.299

HAGENGUTH, J.H., "THE LIGHTNING DISCHARGE", IN "COMPENDIUM OF METEOROLOGY", AMER. METEOROL.SOC., T.F.MALONE-ED., BOSTON, 1951, PG.136

HAGENGUTH, J. AND J.G.ANDERSON, "UNAVAILABLE-TITLE UNKNOWN", A.I.E.E.E., 71,PT.3, 1952,PG.641

HAHN, P., "EIGENTHUMLICHER KUGELBLITZ", ANN.HYDRO.MARIT.METEOROL., 20,1892,PG.257

HAIDINGER, W.VON, "ELEKTRISCHE METEORE AM 20.OCTOBER 1868 IN WIEN BEOBACHTET", SITZBER.MATH.NATURWISS.KGL.AKAD.WEISS.WIEN, II,58,1868a,PG.761

HAIDINGER, W.VON, "DIE SUDWESTLICHEN BLITZKUGELN AM 20.OKTOBER 1868", SITZBER. MATH.NATURWISS.KGL.AKAD.WISS.,WIEN, II,58,1868b,PG.955 (*)

HAIDINGER, W.VON, "EIN KUGELFORMIGER BLITZ, AM 30.AUGUST 1865 GESEHEN ZU FEISTRITZ BEI PEGGAU IN STEIERMARK", SITZBER.MATH.NATURWISS.KGL.AKAD.WISS.WIEN., II,58,1868c,PG.1045

HAIDINGER, W.VON, "EIN KUGELFORMIGER BLITZ AM 30 AUGUST 1865 GESEHEN ZU FEISTRITZ BEI PEGGAU IN STEIERMARK", (SUMMARY), FORTSCHR.PHYS., 25,1869a,PG.961

HAIDINGER, W.VON, "ELEKTRISCHE METEORE AM 20. OKTOBER 1868 IN WIEN BEOBACHTET", (SUMMARY), FORTSCHR.PHYS., 25,1869b,PG.961

HAIDINGER, W.VON, "DIE SUDWESTLICHEN BLITZKUGELN AM 20. OKTOBER 1868", (SUMMARY), FORTSCHR.PHYS., 25,1869c,PG.969

HAIDINGER, W.VON, "ELEKTRISCHE MEOTEORE AM 20. OKTOBER 1868 IN WIEN BEOBACHTET", INST.SCI.SOC.FR., 37,1869d,PG.88 (*)

HAIDINGER, W.VON, "EIN KUGELFORMIGER BLITZ AM 30 AUGUST 1865 GESEHEN ZU FEISTRITZ BEI PEGGAU IN STEIERMARK", INST.SCI.SOC.FR., 37,1869e,PG.112 (*)

HAIDINGER, W.VON, "UNAVAILABLE-TITLE UNKNOWN", PHOTOGR.MITT., 39,1902,PG.761

HALLUITTE, K., "ORAGE SUR MER", BULL.SOC.ASTRON.FR., 23,1909a,PG,461

HALLUITTE, K., "ORAGE SUR MER", C.R.HEBD.SEANCES ACAD.SCI., 148,1909b,PG.1066

HALLUITTE, K., "ORAGE REMARQUABLE SUR L'ATLANTIQUE SUD DANS LA NUIT DU 17 AU 18 FEVRIER 1909 PAR 33 DEGRE LAT.S. ET 48 DEGRE LONG.", (SUMMARY), FORTSCHR.PHYS., 65(3),1909c,PG.284

HALLUITTE, K., "ORAGE REMARQUABLE SUR L'ATLANTIQUE-SUD", METEOROLOGIE, 57,1909d, PG.99

HALLUITTE, K., "GEWITTER AUF DEM MEERE", METEOROL.ZEIT., 26,1909e,PG.380

HALTERMANN, H., "UBER ELMSFEUER AUF SEE", JAHRBUCH DER ASTRONOMIE UND GEOPHYSIK, 7,1896,PG.374

HALTERMANN, H., "LE FEU ST ELME EN MER", CIEL ET TERRE, 17,1896/97,PG.482

HAMILTON, C.W., "SUSTAINED, LOCALIZED, PULSED-MICROWAVE DISCHARGE IN AIR", NATURE, 188,1960,PG.1098 (NBL)

HAMILTON, G., "MERKWURDIGE BLITZSCHLAGE IN SCHWEDEN 1", METEOROL.ZEIT., 13,1896, PG.475

HAMILTON, W., "AN ACCOUNT OF THE LATE ERUPTION OF MOUNT VESUVIUS", ROY.SOC.LOND. PHIL.TRANS., 85,1795,PG.73

HANDEL, P.H., "A MASER APPROACH TO BALL LIGHTNING", UNPUBLISHED, DEPT.PHYS., UNIV. MISSOURI, ST.LOUIS,MO.,1974

HANDS, A., "BALL LIGHTNING", ROY.METEOROL.SOC.Q.J., 35,1901,PG.301

HANDS, A., "FIREBALLS", ENGLISH MECH., 90,1909,PG.40

HANN, J., "UNAVAILABLE-TITLE UNKNOWN", NATURWISS., 2,1906,PG.481 (*)

HANN, J.VON, "LEHRBUCH DER METEOROLOGIE", VERLAG VON CHR.HERM.TAUCHNITZ, LEIPZIG, 1926,PG.661

HAPKE, L., "MERKWURDIGE BLITZ", METEOROL.ZEIT., 10,1893,PG.227

HARE, A.T., "GLOBULAR LIGHTNING", ELECTRICAL ENGINEER, 8,1889a,PG.443

HARE, A.T., "GLOBULAR LIGHTNING", NATURE, 40,1889b,PG.415

HARE, C., "GLOBULAR LIGHTNING", NATURE, 19,1878,PG.5

HARE, R., "ON THE CAUSES OF THE INADEQUATE PROTECTION AFFORDED BY LIGHTNING RODS, IN SOME CASES, AND THE MEANS OF INSURING THEIR PERFECT COMPETENCY: ALSO, A REFUTATION OF THE PREVALENT IDEA, THAT METALS ARE PECULIARLY ATTRACTIVE OF ELECTRICITY", AMER.J.SCI., 13,1828,PG.322

HARE, R., "NOTICES OF TORNADOES", AMER.J.SCI.ARTS, 38,1840,PG.73

HARRISON, E.R., "SPHERICAL PLASMOIDS IN LOW PRESSURE ELECTRODELESS DISCHARGES", J.ELECTRON.CONTROL, 5,1958,PG.319 (NBL)

HASENAUER, L., "PERLSCHNURBLITZ", METEOROL.ZEIT., 30,1913,PG.350

HATCH, A.J., "PLASMA STUDIES IN A LOW PRESSURE HIGH FREQUENCY DISCHARGE", SECOND INTERNATIONAL CONFERENCE ON THE PEACEFUL USES OF ATOMIC ENERGY, GENEVA, PROCEEDINGS, CONTROLLED FUSION DEVICES, 32,1958,PG.333 (NBL)

HAWKINS, A.C., "AN OBSERVATION OF BALL LIGHTNING", AMER.J.METEOROL., 25,1944, PG.364

HAWKINS, A.C., "AN OBSERVATION OF BALL LIGHTNING", AMER.J.METEOROL., 47,1946,PG.5

HAYDEN, E., "GLOBULAR LIGHTNING", SCIENCE, 11,1888,PG.110

HEBERT, M., "CAS DE FOUDRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 25,1847,PG.34

HEEN, P.DE, "PROBLEME DE LA THEORIE MECANIQUE DE L'ELECTRICITE", BRUXELLES, 1903, PG.36 (*)

HEIDKE, P., "PERLSCHNURBLITZ IN HAMBURG AM 13 JULI 1932", METEOROL.ZEIT., 49,1932, PG.437

HELMHOLTZ, H.VON, "UNAVAILABLE-TITLE UNKNOWN", VORT.REDEN.BRAUNSCHWEIG., 1,1896, PG.289

HELMONT, J.B.VON, "ORTUS MEDICINAE", AMSTERDAM, ELZEVIR, 1652,PG.74 (*)

HENNIG, R., "UEBER UNGEWOHNLICHE BLITZENTLADUNGEN", (SUMMARY), FORTSCHR.PHYS., 51(3),1895a,PG.398

HENNIG, R., "UEBER UNGEWOHNLICHE BLITZENTLADUNGEN", NATURWISS.WOCH., 10,1895b, PG.65 (*)

HERMAN, J., "ON THE ELECTRICAL PROPERTIES OF BLOWING SNOW", ANNALES DE GEOPHYSIQUE PARIS, 20(3),1964,PG.235 (NBL)

HERNQVIST, K.G., "DISCHARGE MECHANISM OF MERCURY POOL ARCS", J.APPL.PHYS., 27, 1956,PG.1226

HERNQVIST, K.G. AND E.O.JOHNSON, "RETROGRADE MOTION IN GAS DISCHARGE PLASMAS", PHYS.REV., 98,1955,PG.1576

HERRICH, E., "EIN KUGELBLITZ-ERLEBNIS", KOSMOS, 50,1954,PG.265

HERTZ, H., "VERSUCHE UBER DIE GLIMMENTLADUNG", ANN.PHYSIK, 255,1883,PG.782

HESEHUS, N., "UNAVAILABLE-TITLE UNKNOWN", ZH.FIZ.KHIM.OBSH., 8,1876a,PG.311

HESEHUS, N., "UNAVAILABLE-TITLE UNKNOWN", ZH.FIZ.KHIM.OBSH., 8,1876b,PG.356

HESEHUS, N., "UBER DEN KUGELBLITZ", NATSCHNOJE OBOSIENIJA, NO.7,1899,PG.1373 (*)

HESEHUS, N., "UBER DEN KUGELBLITZ", BEIBL.ANN.PHYS., 24,1900a,PG.200

HESEHUS, N., "UEBER DEN KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 56(3),1900b,PG.253

HESEHUS, N., "UBER DEN KUGELBLITZ", METEOROL.ZEIT., 17,1900c,PG.38

HESEHUS, N., "UEBER DEN KUGELBLITZ", PROMETHEUS, 12,1900d,PG.207 (*)

HESEHUS, N., "KUGEL- UND FLAMMENBLITZ ALS BESONDERE ENTLANDUNGSFORMEN DER ATMOSPHARISCHEN ELEKTRIZAT", PHYSIK.ZEIT., 2,1901,PG.578

HESEHUS, N., "SUR LA NATURE DE L'ECLAIR EN BOULE", BULL.SOC.ASTRON.FR., 17,1903, PG.101

HILDEBRANDSSON, H.H., "KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 39(3),1883,PG.518

HILDEBRANDSSON, H.H., "UNAVAILABLE-TITLE UNKNOWN", GAEA, 21,1884a,PG.604

HILDEBRANDSSON, H.H., "FOUDRE GLOBULAIRE", LA NATURE, 12,1884b,PG.302 (*)

HILDEBRANDSSON, H.H., "FOUDRE GLOBULAIRE", METEOROLOGIE, 31,1885,PG.364

HILDEBRANDSSON, H.H., "MERKWURDIGE BLITZSCHLAGE IN SCHWEDEN, NO.1", METEOROL. ZEIT., 13,1896a,PG.475

HILDEBRANDSSON, H.H., "MERKWURDIGE BLITZSCHLAGE IN SCHWEDEN, NO.3", METEOROL. ZEIT., 13,1896b,PG.476

HILDEBRANDSSON, H.H., "PERLSCHNURBLITZ", METEOROL.ZEIT., 26,1909,PG.44

HILL, E., "GLOBULAR LIGHTNING", NATURE, 56,1897,PG.293

HILL, E.L., "BALL LIGHTNING AS PHYSICAL PHENOMENON", J.GEOPHYS.RES., 65,1960, PG.1947

HILL, E.L., "THE PHYSICAL NATURE OF BALL LIGHTNING", AIAA PAPER NO. DP-61-574, AIAA GREAT LAKES DISTRICT MEETING, MINNEAPOLIS, MINN., 19 APR.1961

HILL, E.L., "BALL LIGHTNING", AMER.SCIENTIST, 58,1970,PG.479

HILL, E.R. AND F.D.SOWBY, "RADIATION FROM BALL LIGHTNING", NATURE, 228,1970, PG.1007

HILL, R.H., "DETERMINATION OF CHARGES CONDUCTED IN LIGHTNING STROKES", J.GEOPHYS. RES., 68,1963,PG.1365 (NBL)

HILLINGER, C., "LIGHTNING TESTED AS NEW ENERGY SOURCE", LOS ANGELES TIMES, SUNDAY, APRIL 29,1979,PART 1,PG.4

HOFMANN, U., "KUGELBLITZBEOBACHTUNG", ZEIT.ANGEW.METEOROL., 36,1919,PG.126

HOHN, W., "BEOBACHTUNG EINES KUGELBLITZES", WETTER UND LEBEN, 18,1966,PG.56

HOHR, A., "ZWEI MERKWURDIGE KUGELBLITZER-SCHEINUNGEN", METEOROL.ZEIT., 20,1903, PG.570

HOLL, H., "KUGELBLITZ", (SUMMARY)", FORTSCHR.PHYS., 56(3),1900a,PG.253

HOLL, H., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 17,1900b,PG.191 (*)

HOLMES, M., "THREE DISCHARGES OF BALL LIGHTNING", NATURE, 133,1934a,PG.179

HOLMES, M., "BALL LIGHTNING-THREE DISCHARGES", ROY.ASTRON.SOC.CANADA J., 28,1934b, PG.144

HOLTZER, R.E. AND E.J.WORKMAN, "PHOTOGRAPHS OF UNUSUAL DISCHARGES OCCURRING DURING THUNDERSTORMS", J.APPL.PHYS., 10,1939,PG.659

HOLTZER, R.E., E.J.WORKMAN, AND L.B.SNODDY, "PHOTOGRAPHIC STUDY OF LIGHTNING", J. APPL.PHYS. 9,1938,PG.134

HOMMA, H., "FEUERKUGEL", METEOROL.ZEIT., 18,1901,PG.576

HOPPE, E., "UBER ATMOSPHARISCHE UND GEWITTER-ELEKTRIZITAT", METEOROL.ZEIT., 2, 1885,PG.100

HORN, F. AND C.TILLMAN, "BEOBACHTUNGEN UBER GEWITTER IN BAYERN, WURTTEMBERG UND BADEN WAHREND DES JAHRES 1889", BEOB.METEOROL.STAT.KONIG.BAYERN, 11,1889a, PG.25 (*)

HORN, F. AND C.TILLMAN, "BEOBACHTUNGEN UBER GEWITTER IN BAYERN, WURTTEMBERG UND BADEN WAHREND DES JAHRES 1889", DEUTSCH.METEOROL.JAHRB.BAYERN, 1889b (*)

HORN, F. AND C.TILLMAN, "BEOBACHTUNGEN UBER GEWITTER IN BAYERN, WURTTEMBERG UND BADEN WAHREND DES JAHRES 1889", (SUMMARY), FORTSCHR.PHYS., 46(3),1890,PG.412

HORNER, O.W., "BALL LIGHTNING", METEOROL.MAG., 39,1904,PG.111

HORSTMANN, W., "KUGELBLITZ", METEOROL.ZEIT., 50,1933,PG.508

HORTON, R.E., "UNUSUAL LIGHTNING", MON.WEATHER REV., 49,1921,PG.242

HOWLAND, M., "FREAK LIGHTNING BALL INJURES 29 IN COLCHESTER", THE TIMES ARGUS, BARRE-MONTPELIER, VT., MONDAY,AUGUST 6,1979

HUBERT, P., "TENTATIVE POUR OBSERVER LA FOUDRE EN BOULE DANS LE VOISINAGE D'ECLAIRS DECLENCHES ARTIFICIELLEMENT", RAPPORT DPH/EP/76/349, 5 MAI 1975a, COMMISSARIAT A L'ENERGIE ATOMIQUE, SERVICE D'ELECTRONIQUE PHYSIQUE, CENTER D'ETUDES NUCLEAIRES DE SACLAY, FRANCE

HUBERT, P., "RECHERCHE SUR LA FOUDRE AU MOYEN D'ECLAIRS DECLENCHES ARTIFICIELLEMENT", METEOROLOGIE, 6,1975b,PG.9 (NBL)

HUC, C., "TONNERRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 119,1894,PG.474

HUGUENY, M., "SUR UNE TROMBE OBSERVEE A DIJON LE 25 JUILLET 1845", C.R.HEBD. SEANCES ACAD.SCI., 21,1845,PG.443

HUMBOLDT, A.VON, "KOSMOS, ENTWURF EINER PHYISCHEN WELTBESCHREIBUNG", STUTTGART, J.G.GOTTASCHER, 1845 (*)

HUMBOLDT, A.VON, "COSMOS, A SKETCH OF A PHSICAL DESCRIPTION OF THE UNIVERSE", TRANSLATION BY E.C.OTTE, LONDON, H.G.BOHN, 1864,PG.345

HUMPHREYS, W.J., "PHYSICS OF THE AIR", FRANKLIN INSTITUTE, PHILADELPHIA, 1920

HUMPHREYS, W.J., "BALL LIGHTNING", SCIENCE, 60,1924,PG.135

HUMPHREYS, W.J., "WANTED-REPORTS OF BALL LIGHTNING OBSERVATIONS", SCIENCE NEWS LETT., 20,1931,PG.73

HUMPHREYS, W.J., "BALL LIGHTNING", AMER.PHIL.SOC.PROC., 76,1936,PG.613

HUMPHREYS, W.J., "PHYSICS OF THE AIR", MCGRAW HILL, NEW YORK, 1940,PG.369

HUMPHREYS, W.J., "WAYS OF WEATHER", JACQUES CATTELL PRESS, LANCASTER, PA., 1942, PG.242

HUNNEMAN, M.E., "A FIRE-BALL", SCIENCE, 86,1937,PG.244

INDRIKSON, T., "KUGELFORMIGE ELEKTRISCHE FUNKEN", BEIBL.ANN.PHYS., 23,1900a,PG.706

INTRIKSON, T., "SHAROOBRAZENYA ELEKTRICHESKAYA ISKRY", ZH.FIZ.KHIM.OBSH., 32, 1900b,PG.53

ISRAEL, H., "DAS GEWITTER, ERGEBNISSE UND PROBLEME DER MODERNEN GEWITTERFORSCHUNG", PROBLEME DER KOSMISCHEN PHYSIK, AKADEMISCHE VERLAGSGESELLSCHAFT, GEEST UND PORTIG, K-G, LEIPZIG, 1950,PG.232

ISRAEL, H., "ATMOSPHAERISCHE ELEKTRIZITAT", AKADEMISCHE VERLAGSGESELLSCHAFT, GEEST UND PORTIG, K.-G., LEIPZIG, 1957 (NBL)

ISRAEL, H., "BLITZPHOTOGRAPHIE", UMSCHAU, 58,1958,PG.586

ISRAEL, H., "KUGELBLITZ-AUFNAHMEN", PHYSIK.BLATTER, 16,1960,PG.348

ISRAEL, H., "ATMOSPHERIC ELECTRICITY", KETER PRESS, JERUSALEM, 1971 (NBL)

ISRAEL, H., M.TOEPLER AND O.TRIER, "UBER FRAGEN DES KUGELBLITZES", PHYS.BLATTER, 16,1960,PG.348

IUR'EV, A., "SECRET OF THE BURNING BALL", KOMSOM.PRAVDA, OCT.30,1960,PG.3, ENGLISH TRANSLATION IN AFCRL-21, USA GOVERNMENT PUBLICATION, AD-251773,1961

IWANOVSKY, A., "THE ENERGY OF BALL LIGHTNING", FOREIGN SCIENCE BULL., 1,NO.12, 1965a,PG.19

IWANOVSKY, A., "SOVIET RESEARCH ON BALL LIGHTNING", FOREIGN SCIENCE BULL., 1,NO.10 1965b,PG.30

IWANOVSKY, A., "A NEW THEORY OF BALL LIGHTNING", FOREIGN SCIENCE BULL., 4,NO.6, 1968,PG.21

JACKEL, W., "KUGELBLITZ IN LAESGEN, KREIS GRUNBERG IN SCHLESIEN AM 23.APRIL 1904", (SUMMARY), FORTSCHR.PHYS., 60(3),1904a,PG.310

JACKEL, W., "KEGELBLITZ IN LAESGEN DREIS GRUNBERG IN SCHLESIEN AM 23.APRIL 1904", ZEIT.ANGEW.METEOROL., 21,1904b,PG.119 (*)

JAEGER, A., "KUGELBLITZ UBER OBERSCHEFFLENZ KREIS MOSBACH/BADEN AM 16 MAI 1960, UM 22 UHR 30", METEOROL.RUND., 14,1961,PG.31

JAGER, F., "UBER EINIGE ELEKTRISCHE ERSCHEINUNGEN", METEOROL.ZEIT., 9,1892,PG.359

JAMIN, M., "UNAVAILABLE-TITLE UNKNOWN", COURS DE PHYSIQUE EXPERIMENTALE ET MATHEMATIQUE, SIGAUD DE LA FORD, LEYDEN, 1,1774,PG.470 (*)

JANEZIC, E., "INTERESSANTER KUGELBLITZ", METEOROL.ZEIT., 25.1908,PG.42

JANS, C.DE, "LES TENTATIVES D'EXPLICATION DE LA FOUDRE GLOBULAIRE", BRUXELLES, 1909a,PG.16 (*)

JANS, C.DE, "LES TENTATIVES D'EXPLICATION DE LA FOUDRE GLOBULAIRE", BULL.SOC. ELECTR.BELGE, 26,1909b,PG.123 (*)

JANS, C.DE, "COUP D'OEIL RETROSPECTIF SUR LES ESSAIS D'EXPLICATION DE LA FOUDRE GLOBULAIRE", CIEL ET TERRE, 31,1910,PG.499

JANS, C.DE, "COUP D'OEIL RETROSPECTIF SUR LES ESSAIS D'EXPLICATION DE LA FOUDRE GLOBULAIRE", CIEL ET TERRE, 32,1911a,PG.155

JANS, C.DE "COUP D'OEIL RETROSPECTIF SUR LES ESSAIS D'EXPLICATION DE LA FOUDRE GLOBULAIRE", CIEL ET TERRE, 32,1911b,PG.255

JANS, C.DE, "COUP D'OEIL RETROSPECTIF SUR LES ESSAIS D'EXPLICATION DE LA FOUDRE GLOBULAIRE", CIEL ET TERRE, 32,1911c,PG.301

JANS, C.DE, "COUP D'OEIL RETROSPECTIF SUR LES ESSAIS D'EXPLICATION DE LA FOUDRE GLOBULAIRE", (SUMMARY), FORTSCHR.PHYS., 67(3),1911d,PG.342

JANS, C.DE, "COUP D'OEIL RETROSPECTIF SUR LES ESSAIS D'EXPLICATION DE LA FOUDRE GLOBULAIRE", BRUXELLES, 1912a,PG.8 (*)

JANS, C.DE, "COUP D'OEIL RETROSPECTIF SUR LES ESSAIS D'EXPLICATION DE LA FOUDRE GLOBULAIRE", CIEL ET TERRE, 33,1912b,PG.18

JANS, C.DE, "COUP D'OEIL RETROSPECTIF SUR LES ESSAIS D'EXPLICATION DE LA FOUDRE GLOBULAIRE", CIEL ET TERRE, 33,1912c,PG.143

JANS, C.DE, "UN CAS REMARQUABLE DE FOUDRE EN BOULE", CIEL ET TERRE, 33,1912d, PG.299

JANS, C.DE, "COUP D'OEIL RETROSPECTIF SUR LES ESSAIS D'EXPLICATION DE LA FOUDRE GLOBULAIRE", (SUMMARY), FORTSCHR.PHYS., 68(3),1912e,PG.318

JEANRENARD, H. AND D.BURNAND, "FEUERKUGEL", (SUMMARY), FORTSCHR.PHYS., 62(3),1906, PG.287

JEANRENARD, H., D.BURNARD AND A.VON BOLZHEIM, "FEUERKUGELN", METEOROL.ZEIT., 23, 1906,PG.330

JEFFERSON, G.T., "A PHOTOGRAPH OF A SUB-SUN", METEOROL.MAG., 92,1963,PG.254 (NBL)

JEFFREYS, H., "RESULTS OF THE BALL LIGHTNING ENQUIRY", METEOROL.MAG., 56,1921, PG.208

JENNINGS, R.C., "PATH OF A THUNDERBOLT", NEW SCIENTIST, 13,1962,PG.156

JENNISON, R.C., "BALL LIGHTNING", NATURE, 224,1969,PG.895

JENNISON, R.C., "BALL LIGHTNING AND AFTER-IMAGES", NATURE, 230,1971,PG.576

JENNISON, R.C., "BALL LIGHTNING", NATURE, 236,1972,PG.278

JENNISON, R.C., "CAN BALL LIGHTNING EXIST IN A VACUUM?", NATURE, 245,1973,PG.95

JENSEN, J.C., "BALL LIGHTNING", PHYSICS(NOW J.APPL.PHYS.), 4,1933a,PG.372

JENSEN, J.C., "BALL LIGHTNING", SCIENTIFIC MONTHLY, 37,1933b,PG.190

JENSEN, J.C., "BALL LIGHTNING", NATURE, 133,1934,PG.95

JESSE, O., "BLITZ VON AUSSERORDENTLICH GROSSEM DURCHMESSER", METEOROLOGIE, 42, 1892a,PG.295

JESSE, O., "BLITZ VON AUSSERORDENTLICH GROSSEM DURCHMESSER", METEOROL.ZEIT., 9, 1892b,PG.434

JOHNSON, E.O., "STUDIES OF EXTERNALLY HEATED HOT CATHODE ARCS, PART I, THE LOW- VOLTAGE FORM OF THE BALL-OF-FIRE MODE (THE LOW-VOLTAGE ARC)", RCA REVIEW, 16, 1955,PG.499 (NBL)

JOHNSON, J.C., "LIGHTNING FORMS", IN "PHYSICAL METEOROLOGY", MIT PRESS, JOHN WILEY AND SONS, INC., NEW YORK, 1954, PG.300-315

JOHNSON, L.H., "BALL LIGHTNING", MARINE OBSERVER, 28,1958,PG.11

JOHNSON, P.O., "BALL LIGHTNING AND SELF-CONTAINING ELECTROMAGNETIC FIELDS", AMER. J.PHYS., 33,1965,PG.119

JOHNSTONE, J., "NOTE", ELECTRICIAN, 25,1890,PG.472

JOLIVET, C., "ECLAIRS EN BOULE", LE COSMOS, 31,1895a,PG.167 (*)

JOLIVET, C., "ECLAIRS EN BOULE", METEOROLOGIE, 43,1895b,PG.171

JONES, A.T., "A LABORATORY ILLUSTRATION OF BALL LIGHTNING", SCIENCE, 31,1910,PG.14 PG.144

JONES, H.S., "BALL LIGHTNING", LONDON DAILY MAIL, 5 NOV. 1936

JONES, I., "GIANT BALL LIGHTNING", J.METEOROL., 2(21),1977,PG.271

JONES, W.N., "BALL LIGHTNING", NATURE, 130,1932,PG.545

JOUBERT, J., "UNAVAILABLE-TITLE UNKNOWN", TRAIT.ELEM.ELECT., 1881,PG.586

JOULE, B.J.B., "ON A REMARKABLE FLASH OF LIGHTNING", NATURE, 18,1878,PG.260

JOULE, J.P., "ON A REMARKABLE APPEARANCE OF LIGHTNING", PHIL.MAG., 37,1850,PG.127

KAHLER, K., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 41,1924,PG.95

KAISER, J., "BALL LIGHTNING", SCIENCE, 60,1924,PG.293

KALES, J.W., "UNAVAILABLE-TITLE UNKNOWN", WESTERN ELECTRICIAN, 26,1900,PG.129

KAPITZA, P.L., "O PRIRODA SHAROVOI MOLNII", DOKL.AKAD.NAUK.SSSR, 101,1955,PG.245

KAPITZA, P.L., "UBER DIE NATUR DES KUGELBLITZES", PHYS.BLATTER, 14,1958,PG.11

KAPITZA, P.L., "THE NATURE OF BALL LIGHTNING", IN "BALL LIGHTNING", D.J.RITCHIE- ED., CONSULTANTS BUREAU, NEW YORK, 1961

KAPITZA, P.L., "ELEKTRONIKA BOL'SHNIK MOSHCHNOSTEI", USP.FIZ.NAUK., 78,1962,PG.181

KAPITZA, P., "SHAROVAYA MOLINIYA I RADIOIZLUCHENIE LINEINYKH MOLNII", ZH.TEKH. FIZ., 38,1968,PG.1829

KAPITZA, P.L., "BALL LIGHTNING AND RADIO EMISSION FROM LINEAR LIGHTNING", SOV. PHYS.TECH.PHYS., 13(11),1969,PG.1475, ENGLISH TRANSLATION OF ZH.TIKH.FIZ., 38, 1968,PG.1829

KAPITZA, P.L., "FREE PLASMA FILAMENT IN A HIGH FREQUENCY FIELD AT HIGH PRESSURE", SOV.PHYS.JETP, 30,1970a,PG.973, ENGLISH TRANSLATION OF ZH.EKSP.TEOR.FIZ., 57(6), 1969,PG.1801

KAPITZA, P.L., "A THERMONUCLEAR REACTOR WITH A PLASMA FILAMENT FREELY FLOATING IN A HIGH FREQUENCY FIELD", SOV.PHYS.JETP, 31,1970b,PG.199, ENGLISH TRANSLATION OF ZH.EKSP.TEOR.FIZ., 58,1970,PG.377

KAPUSCHA, C., "MERWURDIGE BLITZ", METEOROL.ZEIT., 13,1896,PG.279

KARUVE, A.DE, "UNAVAILABLE-TITLE UNKNOWN", TRAIT.ELECTR.TH.APPL., 3,1858,PG.197

KASSNER, C., "KUGELBLITZ?", ZEIT.ANGEW.METEOROL., 60,1943,PG.59

KAUBLER, R., "BEOBACHTUNG EINES KUGELBLITZES", PHYSIK.BLATT., 19,NO.8,1963,PG.374

KAYSER, H., "UNAVAILABLE-TITLE UNKNOWN", MONAT.BER.BERLIN AKAD., NOV.1884a,PG.613

KAYSER, H., "UNAVAILABLE-TITLE UNKNOWN", SITZ.KONIGL.PREUSS.AKAD.WISS.BERLIN, 1884b,PG.1119

KAYSER, H., "UEBER BLITZPHOTOGRAPHIEN", ANN.PHYSIK, 25,1885,PG.131 (NBL)

KEIL, K., "HANDWORTERBUCH DER METEOROLOGY", F.KNAPP, FRANKFURT A.M., 1950,PG.306

KEKEZ, M.M. AND P.SAVIC, "THE GLOW (SPARK) DISCHARGE ELECTROLYSIS-COMBUSTION CONCEPT OF BALL LIGHTNING", PROC. 13TH INTERNATIONAL CONF. PHENOMENA IN IONIZED GASES, PT. 1, BERLIN, DDR, 12-17 SEPT.1977,PG.395

KELVIN, M., "UNAVAILABLE-TITLE UNKNOWN", PROC.GLASGOW PHIL.SOC., 26,1895,PG.233

KENVAN, G., "THE TRAGEDY OF PELEE", THE OUTLOOK, NEW YORK, 71,1902,PG.115 (*)

KERKHOFF, L., "EIN BEITRAG ZUM KAPITEL KUGELBLITZ", ZEIT.ANGEW.METEOROL., 30,1913, PG.286

KHALATOW, S. AND D.KHALATOW, "ECLAIR EN BOULE", BULL.SOC.ASTRON.FR., 21,1907, PG.452

KHAZEN, A.M., "SHAROVAIA MOLNIIA - STATSIONARNOE SOSTOIANIE, PODVOD ENERGII USLOVIIA VOZNIKNOVENIIA", DOKL.AKAD.NAUK.SSSR, 235,1977a,PG.288

KHAZEN, A.M., "BALL LIGHTNING: STATIONARY STATE ENERGY SUPPLY, CONDITIONS OF OCCURENCE", SOV.PHYS.DOKL., 22(7),1977b,PG.371, TRANSLATION OF DOKL.NAUK. SSSR, 235,1977,PG.288

KILBURN-SCOTT, M., "GLOBULAR LIGHTNING", NATURE, 112,1923,PG.760

KILINSKI, K.VON, "LEHRBUCH DER LUFTELEKTRIZITAT", AKADEMISCHE VERLAGS- GESELLSCHAFT, GEEST UND PORTIG, K-G, LEIPZIG, 1958

KIMPARA, A., "ELECTROMAGNETIC ENERGY RADIATED FROM LIGHTNING", IN "PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY", S.C.CORONITI-ED., ELSEVIER, AMSTERDAM, 1965, PG.352

KING, E., "ACCOUNT OF THE EFFECTS OF LIGHTNING AT STEEPLE ASHTON, AND HOLT IN THE COUNTY OF WILTS ON THE 20TH OF JUNE 1772", ROY.METEOROL.SOC.PHIL.TRANS., 63, 1773,PG.231

KING, M.B., "ENERGY SOURCE IMPLICATION OF A HELICON TOROID MODEL FOR BALL LIGHTNING", VFRC-QPR, NO.18,AUGUST,1976a,PG.109

KING, M.B., "AN EXPERIMENT TO CREATE BALL LIGHTNING", VFRC-QPR,NO.22,1976b,PG.70

KINGSTON, H.R., "ANOTHER CASE OF BALL LIGHTNING", ROY.ASTRON.SOC.CANADA J., 25, 1931,PG.420

KIRCHERUS, A., "O ONDERAARDSE WEERELD", AMSTERDAM, 1,1682,PG.279 (*)

KLASS, P.J., "PLASMA THEORY MAY EXPLAIN MANY UFO'S", AVIATION WEEK AND SPACE TECHNOLOGY, AUG. 22, 75(23),1961,PG.52

KLASS, P.J., "MANY UFO'S ARE IDENTIFIED AS PLASMAS", AVIATION WEEK AND SPACE TECHNOLOGY, OCT.3, 85(14),1966,PG.54

KLASS, P.A., "UFO-S: IDENTIFIED", RANDOM HOUSE, NEW YORK, 1968

KLEIN, J., "RATHESELHAFTE BLITZERSCHEINUNGEN", ZEIT.ANGEW.METEOROL., 14,1897, PG.166 (*)

KLEINER, H., "KUGELBLITZ IN MULLERSDORF, 2.APRIL 1904", (SUMMARY), FORTSCHR.PHYS., 60(3),1904a,PG.311

KLEINER, H., "KUGELBLITZ IN MULLERSDORF, 2.APRIL 1904", ZEIT.ANGEW.METEOROL., 21, 1904b,PG.118 (*)

KLOSE, J., "BESCHREIBUNG EINES KUGELBLITZES", ZEIT.FUR METEOROL., 4,1950,PG.91

KNOCHE, W., "UBER ELEKTRISCHE ENTLADUNGEN IN DER KORDILLERE", METEOROL.ZEIT., 26, 1909,PG.355

KNOCHE, W., "UNKNOWN-TITLE UNAVAILABLE", ANN.SOC.CIENT.ARGENTINA, 134,1942,PG.237

KOCH, T., "METEOROLOGISCHE NOTIZEN UND KORRESPONDENZEN", ZEIT.ANGEW.METEOROL., 7, 1890,PG.165

KOECHLIN, J., "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, NO.2628,1924

KOGAN-BELETSKII, G.I., "K VOPROSU O PRIRODA SHAROVOI MOLNII", PRIRODA, NO.4, 1957, PG.71

KOGAN-BELETSKII, G.I., "ON THE QUESTION OF THE NATURE OF BALL LIGHTNING", AIR FORCE CAMBRIDGE RESEARCH LAB REPORT, AFCRL-TN-59-795, 1959

KOGAN-BELETSKII, G.I., "THE NATURE OF BALL LIGHTNING", IN "BALL LIGHTNING", D.J. RITCHIE-EDITOR, CONSULTANTS BUREAU, NEW YORK, 1961

KOHL, T., "UNAVAILABLE-TITLE UNKNOWN", GAEA, 18,1882,PG.569

KOHL, T., "UEBER DEN KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 40(3),1884,PG.663

KOHL, T., "KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 41(3),1885,PG.651

KOHLBERG, O.A., "KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 57(3),1901a,PG.260

KOHLBERG, O.A., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 18,1901b,PG.24 (*)

KOLDAMASOV, A., "BALL LIGHTNING IN LIQUIDS", TEKH.MOLOD., NO.8,1972,PG.24 (*)

KOLLERT, H., "UNAVAILABLE-TITLE UNKNOWN", ELEKTRO.ZEIT., 10,1889

KOLOBKOV, N.V., "GROZY I SHKVALY", GOS.IZDAT.TEKH.-TEOR.LIT., MOSCOW ,1951, PG.47 (*)

KOLOC, P.M., "A NEW MODEL FOR BALL LIGHTNING", NEOPHYSICS RESEARCH, LTD, BOX 222, COLLEGE PARK, MD, 20740, UNPUBLISHED, 1977

KONIECZNY, J., "NEW WEAPON X - BALL SHAPED THUNDER (GLOBULAR FIRE-BALLS)", PRZEGLAD LOTNICZY, 2,1963,PG.72 (*)

KOPPEN, W., "BERMERKENSWERTHE BLITZSCHLAGE", METEOROL.ZEIT., 5,1888a,PG.158

KOPPEN, W., "BERMERKENSWERTHE BLITZSCHLAGE", METEOROL.ZEIT., 5,1888b,PG.202

KOPPEN, W., "KUGELBLITZ UND FOHN IN DER KRIM", METEOROL.ZEIT., 43,1926,PG.33

KOSAREV, E.L. AND YU.G.SEREZHKIN, "NARROW-BAND DECIMETER RADIATION FROM LIGHTNING", SOV.PHYS.TECH.PHYS., 19(2),1974,PG.229, TRANSLATION OF ZH.TEKH.FIZ., 44,1974,PG.364

KOSAREV, E.L., A.B.VAGANOV, B.S.ZAKIROV, L.B.LUGANSKII, E.A.NARUSBEK AND V.N.SAMOSYUK, "RESULTS OF AN EXPEDITION TO STUDY RADIO EMISSION IN THE DECIMETER RANGE ACCOMPANYING LINEAR LIGHTNING", SOV.PHYS.-TECH.PHYS., 14,1969,PG.1477, TRANSLATION OF ZH.TEKH.FIZ., 38(11),1968,PG.1831

KOZLOV, B.N., "PRINCIPLES OF THE RELAXATION THEORY OF BALL LIGHNING", SOV.PHYS. DOKL., 20(4),1976,PG.261, TRANSLATION OF DOKL.AKAD.NAUK SSSR, 221(4),1975,PG.802

KOZLOV, B.N., "O MAKSIMAL'NOM ENERGOVYDELENII SHAROVOI MOLNII", DOKL.AKAD.NAUK. SSSR, 238,1978a,PG.61

KOZLOV, B.N., "TEORIIA SHAROVOI MOLNII", FIZ.PLAZMY, 4,1978b,PG.159 (*)

KOZLOV, B.N., "A THEORY OF BALL LIGHTNING", SOV.J.PLASMA PHYS., 4,1978c,PG.91 (*)

KOZLOV, B.N., "MAXUUM ENERGY LIBERATED BY BALL LIGHTNING", SOV.PHYS.DOKL., 23(1), 1978d,PG.41, TRANSLATION OF DOKL.AKAD.NAUK.SSSR, 238(1-3),1978,PG.61

KRAEMER, H., "DIE ENTSTEHUNG EINES GEWITTERS", IN "WELTALL UND MENSCHEIT", METZGER UND WITTIG, LEIPZIG, INSERT BILD IV, OPPOSITE PG.XII

KREBS, W., "LES ECLAIRS EN BOULE ET LA QUESTION DE LA PROTECTION CONTRE LA FOUDRE", CIEL ET TERRE, 33,1912,PG.257

KRIDER, E.P., C.D.WEIDMAN AND R.C.NOGGLE, "THE ELECTRIC FIELD PRODUCED BY LIGHTNING STEPPED LEADERS", J.GEOPHYS.RES., 82(6),1977,PG.951 (NBL)

KRIRSKY, L., "ZARE PO BLESCICH U VZDALENE VOURKY", METEOROLOGICKE ZPRAVY (PRAGUE), 11(16),1958,PG.167

KRUMMEL, H., "UEBER DAS AUFTRETEN VON KUGELBLITZEN BEI DEM GEWITTER AM 21 JULI 1965 IN MARQUARDT BEI POTSDAM", ZEIT.METEOROL., 19,1966,PG.112

KRUSKAL, M. AND M.SCHWARZSCHILD, "SOME INSTABILITIES OF A COMPLETELY IONIZED PLASMA", PROC.ROY.SOC.(LONDON), A223,1954,PG.348

KUDRYAVYEV, V.V., "M.V.LOMONOSOV", IZDATEL'STVO, MOSCOW, 1955 AND 1961

KUHN, E., "EIN KUGELBLITZ AUF EINER MOMENT-AUFNAHME?", NATURWISS., 38,1951,PG.518

KUSCHEWITZ, H., "KUGELBLITZ", ELEKTRO.ZEIT., 26(35),1905,PG.829

LACROIX, A., "LA MONTAGNE PELEE ET SES ERUPTIONS", PARIS, MASSON ET CIE, 1904, CHAPTER 10 (*)

LADIKOV, Y.P., "MAGNETO-VORTEX RINGS", IZV.AKAD.NAUK.SSSR NO.4,1960,PG.7, ENGLISH TRANS. IN "BALL LIGHTNING", D.J.RITCHIE-ED, CONSULTANTS BUREAU, NEW YORK, 1961

LALANDE, M.DE, "FAILS OBSERVES A LA STATION DE BEUZEVILLE PENDANT L'ORAGE DU 17 MAI", C.R.HEBD.SEANCES ACAD.SCI., 35,1852,PG.24

LALUNG, A., "CORRESPONDANCE - CURIEUX CAS DE FOUDRE EN BOULE", BULL.SOC.ASTRON. FR., 13,1899a,PG.471

LALUNG, A., "LA FOUDRE GLOBULAIRE AUX BUREAUX DU CABLE FRANCAIS", BULL.SOC.ASTRON. FR., 13,1899b,PG.500

LANCASTER, A., "UNAVAILABLE-TITLE UNKNOWN", ANN.OBSER.ROY.BRUXELLES, 1878,PG.279

LANCASTER, A., "LES ORAGES", CIEL ET TERRE, 9,1888/89,PG.193

LANCASTER, A., "COUPS DE FOUDRE", CIEL ET TERRE, 26,1905,PG.241

LANE, F.W., "THE ELEMENTS RAGE", CHILTON, NEW YORK, 1965

LANGMUIR, I., "LIGHTNING PHENOMENA", MON.WEATHER REV., 35,1907,PG.357

LARDRY, M., "DEUX CAS DE FOUDRE GLOBULAIRE", LA METEOROLOGIE, 5,1929,PG.278

LASKOWSKI, B.R., "BALL LIGHTNING", TYCOS, 17,1927,PG.16 (*)

LATHEM, J., "THE ELECTRIFICATION OF SNOWSTORMS AND SANDSTORMS", ROY.METEOROL.SOC. Q.J., 90,1964,PG.91 (NBL)

LAUGIER, A., "EFFETS PRODUITS PAR UN COUP DE FOUDRE A RAMBOUILLET", C.R.HEBD. SEANCES ACAD.SCI., 97,1883a,PG.1160

LAUGIER, A., "EFFETS PRODUITS PAR UN COUP DE FOUDRE A RAMBOUILLET", (SUMMARY), FORTSCHR.PHYS., 39(3),1883b,PG.523

LAZARIDES, M., "LIGHTNING BALLS", NATURE, 231,1971,PG.134

LECONTE, L., "OBSERVATION DE FOUDRE EN BOULE", METEOROLOGIE, 39,1891,PG.353

LEDUC, S., "WANDERNDE KUGELFORMIGE FUNKEN", BEIBL.ANN.PHYS., 23,1899a,PG.680

LEDUC, S., "ETINCELLE GLOBULAIRE AMBULANTE", C.R.HEBD.SEANCES ACAD.SCI., 129, 1899b,PG.37

LEDUC, S., "UNAVAILABLE-TITLE UNKNOWN", L'ECLAIRAGE ELECTRIQUE, 21,1899c,PG.142

LEDUC, S., "UNAVAILABLE-TITLE UNKNOWN", L'ECLAIRAGE ELECTRIQUE, 29,1901,PG.54

LEDUC, S., "ETINCELLE GLOBULAIRE AMBULANTE", BULL.SOC.ASTRON.FR., 16,1902,PG.546 L.LECONTE, "OBSERVATION DE FOUDRE EN BOULE", LA NATURE, NOV.1891,PG.408 (*)

LEMONNIER, M., "FOUDRE EN BOULE", LE COSMOS, JUIN,1891a,PG.282 (*)

LEMONNIER, M., "FOUDRE EN BOULE", METEOROLOGIE, 39,1891b,PG.200

LEONOV, R.A., "ZAGADKA SHAROVYOY MOLNII", NAUKA PRESS, USSR, 1965a (*)

LEONOV, R.A., "THE RIDDLE OF BALL LIGHTNING", U.S.DEPT.COMMERCE, TT-66-33253, JPRS:36823, 3AUG.1965b

LEONOV, R.A., "THE ENIGMA OF BALL LIGHTNING", REPORT ON "ZAGADKA SHAROVOY MOLNII", MOSKVA, IZD-VO, NAUKA, 1965, IN FOREIGN SCIENCE BULL., 2,NO.5,1966,PG.47

LEPEL, F.VON, "UEBER DIE FEUCHTEN FUNKENROHREN UND DIE GEWITTERBLITZ", METEOROL. ZEIT., 6,1889,PG.216

LEPEL, F.VON, "UNAVAILABLE-TITLE UNKNOWN", ELEKTRO.ZEIT., 10,1890a,PG.487

LEPEL, F.VON, "UEBER WANDERNDE FUNKEN", (SUMMARY), FORTSCHR.PHYS., 46(3),1890b, PG.420

LEPEL, F.VON, "UEBER WANDERNDE FUNKEN", METEOROL.ZEIT., 7,1890c,PG.297

LEPEL, F.VON, "UEBER WANDERNDE FUNKEN", METEOROLOGIE, 40,1892,PG.165

LESS, E., "KUGELBLITZ UBER WOLKEN", METEOROL.ZEIT., 18,1901,PG.39

LETZMANN, H., "KUGELBLITZ IN ESTLAND", ZEIT.ANGEW.METEOROL., 55,1938,PG.341 (*)

LEVEILLE, H., "LA FOUDRE EN BOULE", LE COSMOS, DEC.,1891,PG.4 (*)

LEVEILLE, H., "LA FOUDRE EN BOULE", METEOROLOGIE, 40,1892,PG.64

LEWIS, B. AND G.VON ELBE, "COMBUSTION, FLAMES, AND EXPLOSIONS OF GASES", ACADEMIC PRESS, NEW YORK, 1961 (NBL)

LEWIS, H.W., "BALL LIGHTNING", SCIENTIFIC AMERICAN, 208,1963,PG.107

LILIENFELD, P., "BALL LIGHTNING", NATURE, 226,1970,PG.253

LINDBERG, L., "EXPERIMENTS WITH PLASMA RINGS", NATURE, 185,1960,PG.452

LINDEMANN, G., "VERLETZUNGEN DURCH KUGELBLITZE", KOSMOS, 47,1951,PG.380

LINDHOLM, F., "EINE KUGELBLITZARTIGE ERSCHEINUNG", METEOROL.ZEIT., 44,1927,PG.391

LINING, J., "EXTRACT OF A LETTER FROM JOHN LINING, M.D. OF CHARLES TOWN, IN SOUTH CAROLINA, TO CHARLES PINCKNEY, ESQ.; IN LONDON: WITH HIS ANSWERS TO SEVERAL QUERIES SENT TO HIM CONCERNING HIS EXPERIMENTS OF ELECTRICITY WITH A KITE", ROY. METEOROL.SOC.PHIL.TRANS., 48,1754,PG.757

LIPPMAN, A., "UNAVAILABLE-TITLE UNKNOWN", AERONAUTIK, 1,1911,PG.160

LIST, K., "ELEKTRISCHE ERSCHEINUNGEN BEI DEN VOLKANAUSBRUCHEN IN MITTELAMERIK", METEOROL.ZEIT., 22,1905,PG.139

LIVENS, G.H., "THE THEORY OF ELECTRICITY", CAMBRIDGE UNIVERSITY PRESS, 1918 (NBL)

LOCKYER, W.J.S., "BEADED OR PEARL LIGHTNING WITH A MOVING CAMERA", KNOWLEDGE SCI. NEWS, 4,1907a,PG.121 (*)

LOCKYER, W.J.S., "BEADED OR PEARL LIGHTNING WITH A MOVING CAMERA", KNOWLEDGE SCI. NEWS, 4,1907b,PG.145 (*)

LOCKYER, W.J.S., "BEADED OR PEARL LIGHTNING FLASHES; RIBBON OR BAND LIGHTNING", KNOWLEDGE SCI.NEWS, 5,1908a,PG.53 (*)

LOCKYER, W.J.S., "BEADED OR PEARL LIGHTNING FLASHES; RIBBON OR BAND LIGHTNING", KNOWLEDGE SCI.NEWS, 5,1908b,PG.117 (*)

LOCKYER, W.J.S., "UNAVAILABLE-TITLE UNKNOWN", KNOWLEDGE SCI.NEWS, 5,1908c,PG.151

LODGE, H., "UNAVAILABLE-TITLE UNKNOWN", ELEKTRO.ZEIT., 1,1880,PG.430

LODGE, O., "GLOBULAR LIGHTNING", ELECTRICIAN, 29,1892a,PG.603

LODGE, O., "LIGHTNING CONDUCTORS AND LIGHTNING GUARDS", LONDON, 1892b,PG.138 (*)

LODGE, O., "UNAVAILABLE-TITLE UNKNOWN", L'ECLAIRAGE ELECTRIQUE, 26,1901,PG.58

LODGE, O., "LIGHTNING RESEARCH", ELECTRICIAN, 55,1905,PG.174

LOEB, L.B., "ELECTRICAL CORONAS", UNIVERSITY OF CALIFORNIA PRESS, BERKELEY, 1965 (NBL)

LOEB, L.B., "COMMENTS ON A PAPER BY W.H.ANDERSEN, 'ENERGY SOURCE FOR BALL LIGHTNING'", J.GEOPHYS.RES., 71,1966,PG.676

LOEB, L.B. AND A.F.KIP, "ELECTRICAL DISCHARGES IN AIR AT ATMOSPHERIC PRESSURE. THE NATURE OF THE POSITIVE AND NEGATIVE POINT-TO-PLANE CORONAS AND THE MECHANISM OF SPARK PROPAGATION", J.APPL.PHYS., 10,1939,PG.142 (NBL)

LOGAN, E.A., "WHAT ARE FIREBALLS?", ELECTR.REV.LONDON, 138,1946,PG.381

LOMONOSOV, M., "ORATIO DE METONIS VI ELECTRICA ORTIS", ROYAL ACADEMY OF SCIENCES, PETERSBURG, 1753 (*)

LONG, M., "A BALL LIGHTNING REPORT FROM KENT", J.METEOROL., 3(31),1978,PG.210

LOWKE, J.J., M.A.UMAN, AND R.W.LIEBERMANN, "TOWARD A THEORY OF BALL LIGHTNING", J.GEOPHYS.RES., 74,1969,PG.6887

LUGDUNT, M., "UNAVAILABLE-TITLE UNKNOWN", B.A.MAGNI.RATISB.FP.OPERUM., 2,1651, PG.44 (*)

LUIZET, D., "ELECTRICITE ATMOSPHERIQUE", BULL.SOC.ASTRON.FR., 11,1897,PG.298

LUIZET, D., "OBSERVATION D'UN ECLAIR EN CHAPELET", C.R.HEBD.SEANCES ACAD.SCI., 145,1907,PG.780

LUIZET, D., "PERLSCHNURBLITZ", METEOROL.ZEIT., 25,1908,PG.43

LYNN, W.T., "CORRESPONDENCE", PROC.METEOROL.SOC.LOND., 4,1869,PG.374

MACK, K., "BLITZ MIT DEUTLICH ERKENNBARER FORTPFLANZUNGSRICHTUNG", METEOROL.ZEIT., 18,1901,427

MACLEAN, M., "UNAVAILABLE-TITLE UNKNOWN", PROC.GLASGOW PHIL.SOC., 21,1890,PG.22

MACLEAR, J.P., "BALL LIGHTNING", METEOROL.MAG., 39,1904.PG.187

MAKSIMENKO, V., "VYSTREL SHAROVOIY MOLNIEY", VOYENNYYE ZNANIYA, 7,1964,PG.37

MALAN, D.J., "UNUSUAL TYPES OF LIGHTNING", ANNALES DE GEOPHYSIQUE, 17,1961,PG.388

MALAN, D.J., "PHYSICS OF LIGHTNING", ENGLAND UNIV.PRESS, LONDON, 1963,PG.6

MALONE, T.M., "COMPENDIUM OF METEOROLOGY", AMERICAN METEOROLOGY SOCIETY, BOSTON, 1951,PG.141

MALSCH, W., "BEOBACHTUNG EINER SCHWACHEN TROMBE UND EINES KUGELBLITZES", METEOROL. RUND., 9(7,8),1956a,PG.150

MALSCH, W., "BEOBACHTUNG EINER SCHWACHEN TROMBE UND EINES KUGELBLITZES", METEOROL. RUND., 9(9,10),1956b,PG.138

MALTER, L., W.M.WEBSTER, AND E.O.JOHNSON, "STUDIES OF EXTERNALLY HEATED HOT CATHODE ARCS", RCA REVIEW, 12,1951,PG.415 (NBL)

MANCINI, E., "SOPRA UN FENOMENO ANALOGO AL FULMINE GLOBULARE PROVOCATO PER INDUZIONE", ATTI D.REAL.ACCAD.LINCEI, 1,1892,PG.308 (*)

MANCINI, E., "EIN KUGELBLITZFORMIGE ERSCHEINUNG, DIE DURCH INDUKTION ENSTANDEN IST", JAHRBUCH DER ASTRONOMIE UND GEOPHYSIK, 4,1893a,PG.345

MANCINI, E., "KUGELBLITZ", METEOROLOGIE, 43,1893b,PG.322

MANCINI, E., "KUGELBLITZ", METEOROL.ZEIT., 10,1893c,PG.157

MANCINI, E., "UEBER EIN DEM KUGELBLITZ AHNLICHES PHAROMEN, DAS DURCH INDUCTION ENTSTANDEN", NATURWISS.RUND., 8,1893d,PG.62 (*)

MANKIN, R.W., "INSECTS AS UNIDENTIFIED FLYING OBJECTS: AUTHOR'S REPLY TO COMMENTS;2", APPLIED OPTICS, 18(16),1979,PG.2725

MANTEL, G., "BERMERKENSWERTHE BLITZSCHLAGE", METEOROL.ZEIT., 2,1885,PG.18

MARCEL, M.DU, "REPRODUCTION ARTIFICIELLE DES ECLAIRS", METEOROLOGIE, 2,1854,PG.57

MARCET, W., "ON ATMOSPHERIC ELECTRICITY", ROY.METEOROL.SOC.Q.J., 14,1888,PG.197

MARCUSE, A., "ERKPHYSIK-DIE ATMOSPHAERE", IN "WELTALL UND MENSCHHEIT", METZER UND WITTIG, LEIPZIG, PG.450

MARGS, G., "KUGELBLITZ", METEOROL.RUND., 9,1956.PG.72

MARSH, O.C., "GLOBULAR LIGHTNING", NATURE, 53,1895,PG.152

MARSH, O.C., "NOTE ON GLOBULAR LIGHTNING", AMER.J.SCI.ARTS, 151,1896a,PG.13

MARSH, O.C., "GLOBULAR LIGHTNING", (SUMMARY), FORTSCHR.PHYS., 52(3),1896b,PG.301

MARSH, O.C., "KUGELBLITZ", METEOROL.ZEIT., 13,1896c,PG.189

MARSH, O.C., "GLOBULAR LIGHTNING", NATURWISS.RUND., 11,1896d,PG.235 (*)

MARSH, O.C., "KUGELBLITZ", METEOROLOGIE, 47,1899,PG.171

MARSH, O.C., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 19,1902,PG.239

MARTIN, T.C., "THE INVENTIONS, RESEARCHES AND WRITINGS OF NIKOLA TESLA", THE ELECTRICAL ENGINEER, D.VAN NOSTRAND CO., NEW YORK, 1894,PG.167,171

MARTIN, T.H., "LA FOUDRE, L'ELECTRICITE ET LA MAGNETISME CHEZ LES ANCIENS", PARIS, 1866,PG.178,187,288 (*)

MARTYNOV, U.L., "OKISLENIE AZOTA I SHAROVAYA MOLNIYA", UNPUBLISHED, USSR,1970

MARUM, D.VAN, "TWEEDE VERVOLG DER PROEFNEEMINGEN GEDAAN MET TEEYLER'S ELECTRIC MACHINE", HAARLEM, 1795 (*)

MASCART, E., "UNAVAILABLE-TITLE UNKNOWN", TRAIT.ELECT.STATIQUE, 2,1876,PG.563

MASCART, M., "SUR L'EXISTENCE DU TONNERRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 111,1890,PG.496

MASCART, J., "COMMUNICATIONS VERBALES-L'OBSERVATIONS DE FEUX ST.ELME", BULL.SOC. ASTRON.FR., 24,1910,PG.524 (NBL)

MASON, B.J., "CLOUDS, RAIN AND RAINMAKING", CAMBRIDGE UNIVERSITY PRESS, LONDON, CHAPTER 7,1962,PG.112 (NBL)

MASON, C., "FIRE-BALL SEEN IN THE AIR, AND A GREAT EXPLOSION HEARD, DEC 11, 1741", ROY.SOC,.LOND.PHIL.TRANS., 42,1742/43,PG.1

MASON, D., "LIGHTNING STRIKES ON AIRCRAFT-II, ST. ELMO'S FIRE", WEATHER, 19,1964, PG.254

MATHIAS, E., "LA MATIERE FULMINANTE", PARIS, 7,1908,PG.113 (*)

MATHIAS, E., "SUR TROIS OBSERVATIONS D'ECLAIRS EN BOULE FAITES AU SOMMET DU PUY DE DOME", ANN.PHYSIQUE, 5,1916a,PG.365

MATHIAS, E., "SUR TROIS OBSERVATIONS D'ECLAIRS EN BOULE FAITES AU SOMMET DU PUY DE DOME", C.R.HEBD.SEANCES ACAD.SCI., 162,1916b,PG.642

MATHIAS, E., "BALL LIGHTNING ON PUY DE DOME", MON.WEATHER REV., 44,1916c,PG.516

MATHIAS, E., "SUR LES FORMES TERMINALES DES ECLAIRS FULGURANTS", C.R.HEBD.SEANCES ACAD.SCI., 179,1924a,PG.136

MATHIAS, E., "SUR LE BRUIT DE L'ECLAIR", C.R.HEBD.SEANCES ACAD.SCI., 179,1924b, PG.372

MATHIAS, E., "RETOUR SUR LA THEORIE DE L'ECLAIR FULGURANT", C.R.HEBD.SEANCES ACAD. SCI., 179,1924c,PG.550

MATHIAS, E., "TRAITE D'ELECTRICITE ATMOSPHERIQUE ET TELLURIQUE", UNIV.FRANCE PRESS PARIS, 1924d,PG.296

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE: I.LES HETEROGENEITES THERMIQUES", C.R.HEBD.SEANCES ACAD.SCI., 181,1925a,PG.1038

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE: LA COULEUR. HETEROGENEITES CHIMIQUES", C.R.HEBD.SEANCES ACAD.SCI., 181,1925b,PG.1111

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE: LES GLOBES NOIRS ET BLANCS SANS LUMIERE PROPRE", C.R.HEBD.SEANCES ACAD.SCI., 182,1926a,PG.32

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE: L'ENERGIE PAR CENTIMETRE CUBE ET PAR GRAMME AU MOMENT DE L'EXPLOSION", C.R.HEBD.SEANCES ACAD. SCI., 182,1926b,PG.194

MATHIAS, E., "LA FOUDRE, SES DIFFERENTES FORMES, LA MATIERE FULMINANTE", ANN.POST. TELEG.TELEP., 16,1927a,PG.965 (*)

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE. DECOMPOSITION SPONTANEE ET SANS BRUIT SENSIBLE DE CERTAINS ECLAIRS SPHERIQUES DE GRAND DIAMETER", C.R.HEBD.SEANCES ACAD.SCI., 184,1927b,PG.312

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE: EXEMPLES DE DECOMPOSITION SPONTANEE", C.R.HEBD.SEANCES ACAD.SCI., 184,1927c,PG.565

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE. CELLE-CI EST-ELLE CHAUDE OU FROIDE?", C.R.HEBD.SEANCES ACAD.SCI., 184,1927d,PG.653

MATHIAS, E., "UNAVAILABLE-TITLE UNKNOWN", ANN.POST.TELEG.TELEP., JUILLET,1928a (*)

MATHIAS, E., "SUR UNE CURIEUSE PHOTOGRAPHIE D'ECLAIR OBTENUE DANS LA REGION DU LUC DES QUATRE-CANTONS", C.R.HEBD.SEANCES ACAD.SCI., 186,1928b,PG.1334

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE; SON EXPLOSION PAR CHOC", C.R.HEBD.SEANCES ACAD.SCI., 188,1929a,PG.1208

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE: LA TENSION SUPERFICIELLE. PARTAGE D' UN GLOBE EN PLUSIEURS AUTRES SANS L' INFLUENCE D'UN CHOC OU D'UN REBONDISSEMENT", C.R.HEBD.SEANCES ACAD.SCI., 189,1929b,PG.512

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE. ABAISSEMENT DE SA TENSION SUPERFICIELLE PAR DES IMPURETES", C.R.HEBD.SEANCES ACAD.SCI., 189,1929c, PG.607

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE. LES FORMES SERPENTINES", C.R.HEBD.SEANCES ACAD.SCI., 189,1929d,PG.813

MATHIAS, E., "CONTRIBUTION A L'ETUDE DE LA MATIERE FULMINANTE. LES GLOBES EXCAVATEURS", C.R.HEBD.SEANCES ACAD.SCI., 189,1929e,PG.1049

MATHIAS, E., "LA FOUDRE GLOBULAIRE", BULL.MENS.SOC.FR.ELECTR., 10,1930a,PG.22 (*)

MATHIAS, E., "LA FOUDRE ET SES DIFFERENTES FORMES", BULL.SOC.ASTRON.FR., 44,1930b, PG.416

MATHIAS, E., "MONOGRAPHIE DE L'ECLAIR FULGURANT. COMPLEMENTS RELATIFS A SES FORMES TERMINALES. REMARQUES SUR LA PRESSION ELECTROSTATIQUE DES FOUDRES SPHERIQUES", C.R.HEBD.SEANCES ACAD.SCI., 191,1930c,PG.393

MATHIAS, E., "DE LA MATRIERE FULMINANTE", C.R.HEBD.SEANCES ACAD.SCI., 191,1930d, PG.1420

MATHIAS, E., "SUR L'EXISTENCE OU LA NON-EXISTENCE DU FILET DES ECLAIRS EN CHAPELET", C.R.HEBD.SEANCES ACAD.SCI., 192,1931a,PG.653

MATHIAS, E., "SUR L'ECLAIRE EN CHAPELET AVEC GRAINS", C.R.HEBD.SEANCES ACAD. SCI., 193,1931b,PG.1140

MATHIAS, E., "SUR LES ECLAIRS EN CHAPELET AVEC TRAITS", C.R.HEBD.SEANCES ACAD. SCI., 193,1931c,PG.1375

MATHIAS, E., "VARIATION DE LA TENSION SUPERFICIELLE DE LA MATIERE FULMINANTE EN FONCTION DE LA TEMPERATURE ET DU POIDS MOLECULAIRE", C.R.HEBD.SEANCES ACAD. SCI., 194,1932a,PG.413

MATHIAS, E., "LES ECLAIRS GLOBULAIRES ET ASCENDANTS DANS LES MONTAGNES ET LES PLATEAUX ELEVES", C.R.HEBD.SEANCES ACAD.SCI., 194,1932b,PG.2257

MATHIAS, F., "UNAVAILABLE-TITLE UNKNOWN", SOC.FRAN.ELECT.BULL., 2,1932c,PG.729

MATHIAS, E., "LES ECLAIRS EN CHAPELET AVEC GRAINS", BULL.SOC.ASTRON.FR., 47,1933a, PG.82

MATHIAS, E., "ELECTRICITE ATMOSPHERIQUE", C.R.HEBD.SEANCES ACAD.SCI., 196,1933b, PG.654

MATHIAS, E., "SUR LA REALITE DU RESTE D'ECLAIRE SPHERIQUE", C.R.HEBD.SEANCES ACAD. SCI., 197,1933c,PG.962

MATHIAS, E., "SUR LES FOUDRES GLOBULAIRES BLEUES", C.R.HEBD.SEANCES ACAD.SCI., 199,1934a,PG.505

MATHIAS, E., "LA NOTION D'IMPURETE DANS LES FOUDRE GLOBULARIES BLEUES", C.R.HEBD. SEANCES ACAD.SCI., 199,1934b,PG.1083

MATHIAS, E., "AU SUJET DES FOUDRES BLEUES", CIEL ET TERRE, 50,1934c,PG.300

MATHIAS, E., "UNAVAILABLE-TITLE UNKNOWN", MEM.METEOROL.NATUR., NO.24,1934d

MATHIAS, E., "LA THEORIE DE DAUZERE SUR LA CONDUCTIBILITE DE L'AIR DANS LES REGIONS EXPOSEES A LA FOUDRE", C.R.HEBD.SEANCES ACAD.SCI., 201,1935a,PG.314

MATHIAS, E., "LA FOUDRE ET LA FORME GLOBULAIRE", C.R.HEBD.SEANCES ACAD.SCI., 201, 1935b,PG.535

MATHIAS, E., "LA FOUDRE ET SA FORME GLOBULAIRE", MEMORIAL DE L'OFFICE NATIONAL METEOROLOGIQUE DE FRANCE, NO.24, PARIS, 1935c (*)

MATHOUILLOT, H., "DEUX PHOTOGRAPHIES DE FOUDRE GLOBULAIRE", C.R.HEBD.SEANCES ACAD. SCI., 146,1908,PG.603

MATOPA, H.M., "BALL LIGHTNING", PRIRODA, NO.1-6,1962,PG.71

MATTHIAS, B.T. AND S.J.BUCHSBAUM, "PINCHED LIGHTNING", NATURE, 194,1962,PG.327

MATTS, E., "A FIRE BALL?", WEATHER, 19,1964,PG.228

MAUDEMAIN, A., "ECLAIRS EN BOULE", BULL.SOC.ASTRON.FR., 33,1919,PG.284

MAURAIN, C., "ECLAIRS EN BOULE", IN "LA FOUDRE", LIBRAIRIE ARMAND COLIN, 1948, PG.100

MAVROGORDATO, M., "BOLIDES OU FOUDRE EN BOULE", L'ASTRONOMIE, 5,1886a,PG.309 (*)

MAVROGORDATO, M., "BOLIDES OU FOUDRE EN BOULE", METEOROLOGIE, 34,1886b,PG.310

MAXWELL, C., "FLAME OF THE HEAVEN: AN ANTHOLOGY OF BALL LIGHTNING", LONDON; DAVIS, DELPHINE, AND CADE - ED., UNAVAILABLE (*)

MCCANN, R. AND P.KOLOC, "ENERGY OF BALL LIGHTNING", BULL.AMER.PHYS.SOC., 22(9), 1977,PG.1176

MCCLELLAND, J.A., "GLOBULAR LIGHTNING", NATURE, 103,1919,PG.284

MCCROSKY, R.E., "PHENOMENOLOGY OF A BEAD (?) LIGHTNING EVENT", UNPUBLISHED REPORT, SMITHSONIAN INSTITUTION ASTROPHYSICAL OBSERVATORY, NOV.1971

MCCROSKY, R.E. AND H.BOESCHENSTEIN, "THE PRARIE METEORITE NETWORK", SMITHSONIAN ASTROPHYSICAL OBSERVATORY, SPECIAL REPORT, NO.173, 1965 (NBL)

MCDONOUGH, T., "GLOBULAR LIGHTNING", NATURE, "11,1887,PG.62

MCEACHRON, K.B., "UNAVAILABLE-TITLE UNKNOWN", ELECTR.REV., 60,1941,PG.885

MCINTOSH, D.H., "LIGHTNING DAMAGE", WEATHER, 28,1973,PG.160

MCMILLAN, W.G., "ON THE PHENOMENON OF THE LIGHTNING DISCHARGE, AS ILLUSTRATED BY THE STRIKING OF A HOUSE IN COSSIPORE, CALCUTTA", NATURE, 40,1889,PG.295

MCNALLY, J.R., "BALL LIGHTNING - A SURVEY", BULL.AMER.PHYS.SOC., 6,1961,PG.202

MCNALLY, J.R., "PRELIMINARY REPORT ON BALL LIGHTNING", OAK RIDGE NATIONAL LAB REPORT, ORNL-3938, MAY 1966

MEADEN, G.T., "FOUR STORM STORIES FROM STEEPLE ASTON: 1670,1772 AND 1973", WEATHER, 28,1973,PG.520

MEADEN, G.T., "REMARKABLE OCCURRENCE OF UNUSUALLY-SHAPED BALL LIGHTNING, 15 AUGUST 1975", J.METEOROL.(TROWBRIDGE, ENGLAND), 1(10),1976,PG.310 (*)

MEEK, J.M. AND J.D.GRAGGS, "ELECTRICAL BREAKDOWN OF GASES", OXFORD PRESS, LONDON, 1953,PG.242

MEEK, J.M. AND F.R.PERRY, "THE LIGHTNING DISCHARGE", PHYS.SOC.LONDON, RPT.PROG.,PHYS., 10,1946,PG.314

MEESE, A.D. AND E.H.EVANS, "CHARGE TRANSFER IN THE LIGHTNING STROKE AS DETERMINED BY THE MAGNETOGRAPH", J.FRANKLIN INSTITUTE, 273,1962,PG.375 (NBL)

MEINARDUS, W., "UEBER DAS WETTERLEUCHTEN", METEOROL.ZEIT., 12,1894,PG.14

MEISSNER, A., "UBER KUGELBLITZ", METEOROL.ZEIT., 47,1930,PG.17

MENDENHALL, T.C., "ON GLOBULAR LIGHTNING", AMER.J.METEOROL., 6,1890,PG.437

MENIN, H., "UNAVAILABLE-TITLE UNKNOWN", LES MONDES, 56,1881,PG.387

MENSHUTKIN, B.N., "MIKHAILO VASIL'EVICH LOMONOSOV", ZIZNEOPISANIE, IZDANKE, 1911

MENSHUTKIN, B.N., "RUSSIA'S LOMONOSOV", PRINCETON UNIVERSITY PRESS, PRINCETON, NEW JERSEY, 1952

MENZEL, D.H. AND L.G.FORD, "THE WORLD OF FLYING SAUCERS", DOUBLEDAY, NEW YORK, 1965

MERCANTON, P.L., "DE QUELQUES ECLAIRS RARES", LAUSANNE BULL.SOC.VAUD.SCI.NATUR., 63,1945,PG.153 (*)

MERHAUT, O., "EINE BEMERKENSWERTE BLITZAUFNAHME", NATURWISS., 32,1944,PG.212

METTETAL, M., "OBSERVATION D'UN PHENOMENE ELECTRIQUE", C.R.HEBD.SEANCES ACAD.SCI., 121,1895a,PG.596

METTETAL, M., "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 23,1895b,PG.407

METTETAL, M., "KUGELBLITZ", NATURWISS.RUND., 11,1895c,PG.64 (*)

METTETAL, M., "KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 52(3),1896,PG.309

MEUNIER, A., "DOUBLE CAS DE FOUDRE EN BOULE OBSERVE DANS UN TRES-COURT ESPACE DE TEMPS", C.R.HEBD.SEANCES ACAD.SCI., 35,1852a,PG.195

MEUNIER, A., "DOUBLE CAS DE FOUDRE EN BOULE OBSERVE DANS UN TRES-COURT ESPACE DE TEMPS", COSMOS, 1,1852b,PG.351 (*)

MEUNIER, S., "SUBSTANCE SINGULIERE RECUEILLIE A LA SUITE D'UN METEORE RAPPORTE A LA FOUDRE", C.R.HEBD.SEANCES ACAD.SCI., 103,1886,PG.837

MEUNIER, S., "UNAVAILABLE-TITLE UNKNOWN", L'ASTRONOMIE, 6,1887,PG.104

MEUNIER, S., "BEMERKENSWERTHE BLITZSCHLAGE", METEOROLOGIE, 37,1888,PG.167

MEUSBURGER, D., "KUGELBLITZ", METEOROL.ZEIT., 21,1904,PG.283

MEY, A., "KUGELBLITZE", METEOROL.ZEIT., 44,1927,PG.188

MEYER, J., "KUGELBLITZ AM 22 MAI 1897 IN HAMBURG BEOBACHTET", ANN.HYDRO.MARIT. METEOROL., 25,1897,PG.257

MILHAM, W.I., "METEOROLOGY", MACMILLAN, NEW YORK, 1918,PG.470

MILLS, A.A., "BALL LIGHTNING AND THERMOLUNINESCENCE", NATURE, 233,1971,PG.131

MILLS, A.A., "WILL-O'-THE-WISP", CHEM.BRITAIN, 16(2),1980,PG.69

MIMNO, H.R., "BALL LIGHTNING", IEEE TRANS.AERO.ELECT.SYS., 6,1970,PG.846 PG.254

MINCHIN, G.M., "PERSONAL INJURY FROM A FIRE-BALL", NATURE, 53,1895a,PG.5

MINCHIN, G.M., "A FIRE BALL", SCIENTIFIC AMERICAN, 73,1895b,PG.374

MININ, V.F. AND F.K.BAIBULATOV, "THE NATURE OF PEARL LIGHTNING", SOV.PHYS.DOKL., 14(10),1970,PG.979, ENGLISH TRANSLATION OF DOKL.AKAD.NAUK. SSSR, 118(4),1969, PG.795

MOHN, H., "KUGELBLITZ", METEOROL.ZEIT., 25,1908,PG.314

MOHR, F.B., "A TRULY REMARKABLE FLY", SCIENCE, 151,1960,PG.634

MOIGNO, F., "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 14,1859,PG.672

MOLLER, F., "DER GEHEIMNISVOLLE KUGELBLITZ", UMSCHAU, 49,1949,PG.458

MOLLER, F., "UNAVAILABLE-TITLE UNKNOWN", HAMEL EN DAMPKRING, 49,1951a,PG.158

MOLLER, F., "WAS IST EIN KUGELBLITZ?", KOSMOS, 47,1951b,PG.86

MONCEL, T.DU, "NOUVEAU SYSTEME D'INFLAMMATION A DISTANCE DE SUBSTANCE INFLAMMABLES PAR LE COURANT D'UNE PILE DE DANIELL ET DES CONDUCTEURS TRESFINS", C.R.HEBD.SEANCES ACAD.SCI., 37,1853,PG.953

MONCEL, T.DU, "NOTE SUR LES ECLAIRS EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 38, 1854a,PG.408

MONCEL, T.DU, "THEORIE DES ECLAIRS", MEM.SOC.SCI.NAT.CHERBOURG, 2,1854b,PG.49 (*)

MONCEL, T.DU, "UNAVAILABLE-TITLE UNKNOWN", MEM.SOC.SCI.NATUR.CHERBOURG, 2,1854c, PG.85

MONCEL, T.DU, "REPRODUCTION ARTIFICIELLES DES ECLAIRS", METEOROLOGIE, 2,1854d, PG.57

MONCEL, T.DU, "NOTICE HISTORIQUE ET THEORIQUE SUR LE TONNERRE ET LES ECLAIRS", PARIS, 1857,PG.54 (*)

MONCEL, T DU, "ECLAIRS EN BOULE", BULL.SOC.ENCOURAG., NOV.7,1881 (*)

MONCEL, T.DU, "ECLAIRS EN BOULE", (SUMMARY), FORTSCHR.PHYS., 38(3),1882a,PG.556

MONCEL, T.DU, "ECLAIRS EN BOULE", LA LUMIERE ELECTRIQUE, 6,1882b,PG.145 (*)

MONCEL, T.DU, "UNAVAILABLE-TITLE UNKNOWN", LA LUMIERE ELECTRIQUE, 6,1882c,PG.169

MONNOT, M., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 62,1948,PG.323

MOON, F.D., "BALL LIGHTNING", MARINE OBSERVER, 2,1925,PG.129

MOORE, M., "MACHINE MAKES LIGHTNING", BREVARD TODAY, BREVARD COUNTY NEWSPAPER, COCOA BEACH, FLA., JULY 18,1977

MOORSEL, J.VAN, "GLOBULAR LIGHTNING", ELECTRICIAN, 22,1889,PG.520

MORGAN, J.H.W., "BALL LIGHTNING", METEOROL.MAG., 57,1922,PG.46

MORRIS, W., "A THUNDERSTORM MYSTERY", LONDON DAILY MAIL, 5 NOV. 1936

MORTLEY, W.S., "BALL LIGHTNING ENIGMA", NEW SCIENTIST, 57,1973,PG.42

MOTT, F.T., "CURIOUS ELECTRICAL PHENOMENON", NATURE, 22,1880,PG.193

MOUREAUX, T., "ANCIEN EXEMPLE DE FOUDRE EN BOULE", LA NATURE BULL., NO.562, 1887a (*)

MOUREAUX, T., "ANCIEN EXEMPLE DE FOUDRE EN BOULE", METEOROLOGIE, 35,1887b,PG.221

MOUREAUX, T., "FOUDRE GLOBULAIRE", LA NATURE, JUIN,1892a,PG.33 (*)

MOUREAUX, T., "FOUDRE GLOBULAIRE", METEOROLOGIE, 40,1892b,PG.215

MOUSSETTE, C., "THEORIE MECANIQUE DE LA FOUDRE", C.R.HEBD.SEANCES ACAD.SCI., 107, 1884,PG.435

MOUSSETTE, C., "LA FOUDRE EN SPIRALE", C.R.HEBD.SEANCES ACAD.SCI., 103,1886a,PG.30

MOUSSETTE, C., "LA FOUDRE EN SPIRALE", (SUMMARY), FORTSCHR.PHYS., 42(3),1886b, PG.654

MOUSSETTE, C., "LA FOUDRE EN SPIRALE", LA LUMIERE ELECTRIQUE, 21,1886c,PG.123 (*)

MOUSETTE, C., "ORAGES DU 12 MAI 1886, LA FOUDRE EN SPIRALE", METEOROLOGIE, 34, 1886d,PG.298

MOUSSETTE, C., "LA FOUDRE EN SPIRALE", REV.ELECTR., 2,1886e,PG.109 (*)

MOUSSETTE, C., "UNAVAILABLE-TITLE UNKNOWN", LA LUMIERE ELECTRIQUE, 25,1887,PG.534

MUHLEISEN, R., "DER KUGELBLITZ-EIN PLASMAZUSTAND?", KOSMOS, 68,1972,PG.159

MUIRHEAD, H., "GLOBE LIGHTNING", ELECTRICIAN, 12,1883,PG.50

MUIRHEAD, H., "GLOBE LIGHTNING", METEOROL.MAG., 18,1883/84,PG.57

MULLER, M., "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 16,1888,PG.415

MULLER-HILLEBRAND, D., "UNAVAILABLE-TITLE UNKNOWN", TEKN.ZEIT., 85,1955,PG.541

MULLER-HILLEBRAND, D., "ZUR FRAGE DES KUGELBLITZES", ELEKTRIE, 17,1963,PG.211

MULLER-HILLEBRAND, D., "LIGHTNING PROTECTION", IN "PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY", S.C.CORONITI-ED., ELSEVIER, AMSTERDAM, 1965a,PG.407

MULLER-HILLEBRAND, D., "BALL LIGHTNING", IN "PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY", S.C.CORONITI-ED., ELSEVIER, AMSTERDAM, 1965b,PG.455

MURATOV, M., "LOMONOSOV", IZDATEL'STVO, MOSCOW, 1960

MURCHIE, G., "SONG OF THE SKY", RIVERSIDE PRESS, CAMBRIDGE, 1954,PG.218

MUSCHENBROEK, P.VAN, "UNAVAILABLE-TITLE UNKNOWN", COURS DE PHYSIQUE EXPERIMENTALE ET MATHEMATIQUE, SIGAUD DE LA FOND, LEYDEN, 3,1769,PG.405 (*)

MUSYA, K., "ON THE LUMINOUS PHENOMENON THAT ATTENDED THE IDU EARTHQUAKE, NOVEMBER 26TH, 1930", TOKYO UNIV.EARTHQUAKE RES.BULL., 9,1931.PG.177

NABER, H., "KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 53(3),1897,PG.300

NABER, H., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 14,1897,PG.144 (*)

NARTMANN, D., "UNAVAILABLE-TITLE UNKNOWN", L'ASTRONOMIE, 8,1889,PG.90

NASSE, E., "UN EXEMPLE DE FOUDRE GLOBULAIRE OBSERVE A BRIVES, LE VENDREDI 17 MAI", C.R.HEBD.SEANCES ACAD.SCI., 74,1872a,PG.1384

NASSE, E., "FOUDRE GLOBULAIRE A BRIVES, LE VENDREDI 17 MAI", (SUMMARY), FORTSCHR. PHYS., 28,1872b,PG.852

NASSE, E., "FOUDRE GLOBULAIRE A BRIVES, LE VENDREDI 17 MAI", MONDES, 28,1872c, PG.280 (*)

NAUER, H., "MODELLVERSUCHE ZUM KUGELBLITZ", ZEIT.ANGEW.PHYS., 5(12),1953,PG.441

NAUER, H., "WIE ENTSTEHT EIN KUGELBLITZ?", UMSCHAU, 56,1956,PG.75

NEESEN, F., "GEWITTER UND BLITZABLEITER", HIMMEL UND ERDE, 13,1900,PG.151 (*)

NEESEN, F., "UNAVAILABLE-TITLE UNKNOWN", HIMMEL UND ERDE, 13,1901,PG.145

NERNST, H., "UNAVAILABLE-TITLE UNKNOWN", THEOR.CHEM., 6,1909,PG.679

NEUGEBAUER, T., "ZU DEM PROBLEM DES KUGELBLITZES", ZEIT.PHYS., 106(7,8),1937, PG.474

NEUGEBAUER, T., "THE THEORY OF BALL LIGHTNING", FIZ.SZLE.(HUNGARY), 25(2),1975, PG.49 (*)

NEUGEBAUER, T., "ZU DER QUANTENMECHANISCHEN THEORIE DES KUGELBLITZES", ACTA PHYSICA, 42(1),1977,PG.29 (*)

NEUNTENFL, J., "WINTERGEWITTER, ST. ELMSFEUER, UND KUGELBLITZ", WETTER UND LEBEN, 3,1951,PG.49

NEWMAN, M.M., "THUNDERSTORM ELECTRICAL DISCHARGES INTERCEPTED BY AIRCRAFT AND RELATED BALL LIGHTNING AND SPHERICS PHENOMENA", J.GEOPHYS.RES., 65,1960,PG.1966

NEWMAN, M.M., "USE OF TRIGGERED LIGHTNING TO STUDY THE DISCHARGE PROCESS IN THE CHANNEL", IN "PROBLEMS IN ATMOSPHERIC AND SPACE ELECTRICITY", AMERICAN ELSEVIER, NEW YORK, 1965,PG.482 (NBL)

NEWMAN, M.M., "LIGHTNING DISCHARGE SIMULATION AND TRIGGERED LIGHTNING", IN PLANETARY ELECTRODYNAMICS, S.C.CORONITI AND J.HUGHES-EDITORS, GORDON AND BREACH, NEW YORK, 2,1968,PG.213 (NBL)

NEWMAN, M.M., J.R.STAHMAN, J.D.ROBB, E.A.LEWIS, S.G.MARTIN AND S.V.ZINN, "TRIGGERED LIGHTNING STROKES AT VERY CLOSE RANGE", J.GEOPHYS.RES., 72,1967, PG.4761 (NBL)

NEWMAN, W. AND A.O.KEMPPAINEN, "HIGH-VOLTAGE INSTALLATION OF THE PRECIPITATION- STATIC PROJECT", PROC.IRE, 34,1946,PG.247

NICHOLS, J.R., "BELLS THRO' THE AGES", LONDON, CHAPMAN AND HALL, 1928,PG.277

NICHOLSON, M., "AN ACCOUNT OF A STORM OF LIGHTNING OBSERVED ON THE 1ST OF MARCH, 1774, NEAR WEAKFIELD, IN YORKSHIRE", ROY.METEOROL.SOC.PHIL.TRANS., 64,1774, PG.350

NIESE, H., "UNAVAILABLE-TITLE UNKNOWN", START, 16,1948,PG.7

NIESSL, G.VON, "KUGELBLITZBEOBACHTUNG", (SUMMARY), FORTSCHR.PHYS., 54(3),1898a, PG.313

NIESSL, G.VON, "KUGELBLITZBEOBACHTUNG", VERH.NATURF.VER.BRUNN, 36,1898b,PG.41 (*)

NEISSL, G.VON, "ELEKTRISCHE LICHTPHANOMENE AN DEN LEITUNGSDRAHTEN", (SUMMARY), FORTSCHR.PHYS., 57(3),1901a,PG.260

NIESSL, G.VON, "ELEKTRISCHE LICHTPHANOMENE AN DEN LEITUNGSDRAHTEN", VERH.NATURF. VER.BRUNN, 40,1901b (*)

NIPPOLDT, M., "KUGELBLITZ MIT NACHFOLGENDEN BLITZSTRAHL", METEOROL.ZEIT., 33,1916, PG.475

NIXON, J., "A LETTER FROM THE REV MR JOHN NIXON, FRS TO THE PRESIDENT, SERVING TO ACCOMPANY A LETTER FROM MR WILLIAM SMITH TO MR NIXON, GIVING A VERY PARTICULAR ACCOUNT OF THE EARTHQUAKE FELT ON SEPT. 30, 1750", ROY.SOC.LOND.PHIL.TRANS., 46, 1750,PG.727

NOAD, H.M., "UNAVAILABLE-TITLE UNKNOWN", MANUAL OF ELECTRICITY, 1,1855,PG.204

NONHEBEL, G., J.COLVIN, H.S.PATTERSON, AND R.WHYTLAW-GRAY, "THE COAGULATION OF SMOKES AND THE THEORY OF SMOLUCHOWSKI", ROY.SOC.LOND.PROC., 116,1927,PG.540

NORINDER, H., "UNAVAILABLE-TITLE UNKNOWN", TEKN.TIDSKRIFT (STOCKHOLM), 33,1923, PG.190 (*)

NORINDER, H., "OM BLIXTENS NATUR", KUNGLIGA VENTENSKAPSSOCIETETENS ARSBOK, 94, 1939,PG.39

NORINDER, H., "ON THE MEASUREMENT AND NATURE OF ATMOSPHERICS PRODUCED BY ELECTRIC DISCHARGES IN SNOW SQUALLS AND FROM OTHER SOURCES", TELLUS, 1(2),1949,PG.1 (NBL)

NORINDER, H., "COMMENTS", IN "PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY", S.C.CORONITI-ED, ELSEVIER, AMSTERDAM, 1965,PG.455

NORINDER, H. AND R.SIKSNA, "EXPERIMENTS CONCERNING ELECTRIFICATION OF SNOW", ARKIV FOER GEOFYSIK, 2,1953,PG.59

OBERMAYER, A.VON, "UEBER DIE BEI BESCHREIBUNG VON ELMSFEUER NOTWENDIGEN ANGABEN", METEOROL.ZEIT., 5,1888,PG.224 (NBL)

OBERMAYER, A.VON, "ST. ELMSFEUER BEOBACHTUNGEN", JAHRBUCH DER ASTRONOMIE UND GEOPHYSIK, 3,1892,PG.325 (NBL)

OLLENDORF, H., "UNAVAILABLE-TITLE UNKNOWN", ARK.ELEKTR., 27,1933,PG.169

OLTRAMARE, G., "EXPLICATION DU BOLIDE DE GENEVE DU 7 JUIN 1879", C.R.HEBD.SEANCES ACAD.SCI., 88,1879,PG.1319

O'NEILL, J.J., "PRODIGAL GENIUS, THE LIFE OF NIKOLA TESLA", IVES WASHBURN, INC, DAVID MCKAY CO.,INC., NEW YORK, 1971

ORIEL, A., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 15,1901,PG.303

ORVILLE, R.E., "HIGH SPEED, TIME RESOLVED SPECTRUM OF A LIGHTNING STROKE", SCIENCE, 157,1966,PG.451 (NBL)

ORVILLE, R.E., "LIGHTNING BETWEEN CLOUDS AND GROUND", WEATHERWISE, 25,1972, PG.108 (NBL)

OSBORNE, J., "BALL LIGHTNING", J.METEOROL., 3(31),1978,PG.215

OSWALT, P., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 29,1915,PG.437

OTTO, M., "L'ECLAIR EN BOULE", LA NATURE, 29,1901,PG.361 (*)

OWEN, R., "BALL, OR GLOBE LIGHTNING", AMER.J.METEOROL., 3,1886,PG.383

OWENS, A.L., "BALL LIGHTNING", MARINE OBSERVER, 1,1924,PG.117

PAINTER, B.F., "REPRODUCING BALL LIGHTNING", QST, DEC.1920,PG.59

PALAZZO, L., "KUGELBLITZ", METEOROL.ZEIT., 20,1903,PG.188

PALMER, J., "AN ACCOUNT OF THE EFFECTS OF LIGHTNING AT SOUTHMOLTON IN DEVONSHIRE", ROY.SOC.LOND.PHIL.TRANS., 47,1752,PG.330

PANETH, F.A., "THE FREQUENCY OF METEORITE FALL THROUGHOUT THE AGES", VISTAS IN ASTRONOMY, 2,1956,PG.1681

PARADISE, W., "ACCOUNT OF THE EFFECTS OF LIGHTNING AT STEEPLE ASHTON AND HOLT, IN THE COUNTY OF WILTS, ON THE 20TH OF JUNE, 1772", ROY.SOC.LOND.PHIL.TRANS., 63, 1773,PG.240

PARENT, E., "SUR LES EFFETS PRODUITS PAR LA FOUDRE, A TROYES, LE 26 JUILLET 1873; OBSERVATIONS DE NOMBREUX GLOBES DE FEU", C.R.HEBD.SEANCES ACAD.SCI., 77,1873a, PG.370

PARENT, E., "SUR LES EFFETS PRODUITS PAR LA FOUDRE A TROYES, LE 26 JUILLET 1873; OBSERVATIONS DE NOMBREUX GLOBES DE FEU", (SUMMARY), FORTSCHR.PHYS., 29,1873b, PG.1002

PARENT, E., "SUR LES EFFETS PRODUITS PAR LA FOUDRE A TROYES, LE 26 JUILLET 1873; OBSERVATIONS DE NOMBREUX GLOBES DE FEU", MONDES, 31,1873c,PG.716 (*)

PARISOT, M., "SUR QUELQUES PHENOMENES DE METEOROLOGIE OBSERVES A EPINOL, DANS LE DEPARTEMENT DES VOSGES, EN AOUT 1821", ANN.CHIM.PHYS., 19,1821.PG.86

PARRY, A., "SOVIET AFFAIRS", MISSILES AND ROCKETS, 3(4),APRIL,1958a,PG.136

PARRY, A., "SOVIET AFFAIRS", MISSILES AND ROCKETS, 3(6),JUNE,1958b,PG.159

PATTERSON, H.S., R.WHYTLAW-GRAY, AND W.CAWOOD, "THE PROCESS OF COAGULATION IN SMOKES", ROY.SOC.LOND.PROC., 124,1929a,PG.502 (NBL)

PATTERSON, H.S., R.WHYTLAW-GRAY, AND W.CAWOOD, "THE STRUCTURE AND ELECTRIFICATION OF SMOKE PARTICLES", ROY.SOC.LOND.PROC., 124,1929b,PG.523 (NBL)

PAW-U, K.T., "INSECTS AS UNIDENTIFIED FLYING OBJECTS: COMMENT", APPLIED OPTICS, 18(16),1979,PG.2723

PCHOLKO, I.G., "AVIATION METEOROLOGY", FROM "AVIATSIONNAYA METEOROLOGIYA", LENINGRAD, METEOROLOGICHESKOY, IZDATEL'STVO, 1963,PG.239, IN FOREIGN SCIENCE BULL., 2,NO.4,APPENDIX I,1966,PG.50

PEAKE, N.B., "ANTI-BUBBLE BALL LIGHTNING", NEW SCIENTIST, 13,1962,PG.334

PELLISSIER, G., "LES ECLAIRS EN CHAPELET", LA NATURE, 22,1894,PG.323 (*)

PELLETIER, L., "LES FORMES ETRANGES DE LA FOUDRE", REV.CIEL.BOURGES, 1934 (*)

PILLEUX, L., "SUR LE AURORES BOREALES ET LES ECLAIRS EN BOULE", METEOROLOGIE, 43, 1895,PG.249

PELZL, E., "ANLEITUNG FUR DIE BEOBACHTER AN DEN WETTERBEOBACHTUNGSSTELLEN DES METEOROLOGISCHEN UND HYDROLOGISCHEN DIENSTES DER DEUTSCHEN DEMOKRATISCHEN REPUBLIK", VEROFFENTLICHUNGEN DES METEOROLOGISCHEN UND HYDROLOGISCHEN DIENTSTES DER DEUTSCHEN DEMOKRATISCHEN REPUBLIK, AKADEMIE VERLAG, BERLIN, NR.7,1953,PG.136

PEPPLER, W., "EINE MERKWURDIGE KUGELBLITZARTIGE ELEKTRISCHE ENTLADUNG", ZEIT. ANGEW.METEOROL., 36,1919,PG.29

PEROUX, E., "ECLAIR EN BOULE", BULL.SOC ASTRON.FR., 21,1907,PG.453

PERRIN, P., "ETUDE SUR LES ECLAIRS", PARIS, 1873,PG.77 (*)

PETERBAUDE, H., "UNAVAILABLE-TITLE UNKNOWN", PROG.GYMN.HIRSCHBERG, 1888,PG.6

PETERSEN, H., "BALL LIGHTNING", GEOPHYSICA, 5,1954a,PG.49

PETERSEN, H., "BALL LIGHTNING", WEATHER, 9,1954b,PG.73

PETERSEN, H., "PHOTOGRAPHY AND BALL LIGHTNING", WEATHER, 9,1954c,PG.321

PETRIE, W.M.F., "SLOW LIGHTNING", NATURE, 24,1881,PG.284

PETRZ'ILKA, V.A., "BALL LIGHTNING", PRAGUE, INSTITUTE OF PLASMA PHYSICS, CZECHOSLOVAK ACADEMY OF SCIENCE, 1967 (*)

PETRZ'ILKA, V.A., "A POSSIBLE EXPLANATION OF BALL LIGHTNING MOTIONS", CESKOSLOV. CASOPIS FYSIKU, 19,1969,PG.160

PFEIL, H., "DIE HIRSCHBERGER KUGELBLITZE", (SUMMARY), FORTSCHR.PHYS., 42(3),1886a, PG.670

PFEIL, H., "DIE HIRSCHBERGER KUGELBLITZE", GAEA, 1886b,PG.5 (*)

PFLEGEL, R., "BEOBACHTUNG EINES KUGELBLITZES", ZEIT.METEOROL., 10(11),1956,PG.347 PG.347

PHILLIPS, R., "ON ATMOSPHERIC ELECTRICITY", LONDON, HARDWICKE, PICCADILLY,1863, PG.45 (*)

PHILLIPS, R., "GLOBULAR AND OTHER FORMS OF LIGHTNING", NATURE, 41,1889,PG.58

PIERCE, E.T., R.M.NADILE, AND P.J.MCKINNON, "AN INVESTIGATION OF NEGATIVE POINT- PLANE CORONA AND ITS RELATION TO BALL LIGHTNING", AIR FORCE CAMBRIDGE RESEARCH LAB REPORT, AFCRL-TR-60-354, 24 OCT.1960

PIERCE, S. AND E.M.CARLSTEAD, "OBSERVATION OF A CURIOUS ELECTRICAL PHENOMENON IN HAWAII", MON.WEATHER REV., 94,1966,PG.272

PILAYE, M.DE, "FOUDRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 17,1843,PG.630

PILLEUX, L., "SUR LES AURORES BOREALES ET LES ECLAIRS EN BOULE", LE COSMOS, 31, 1895,PG.420 (*)

PIREN, M.C.DE, "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 25,1911,PG.284

PITTOCK, A.B., "COMMENT ON 'ON THE PROBLEM OF BALL LIGHTNING' BY W.I.ARABADJI", J.GEOPHYS.RES., 82(24),1977,PG.3499

PLANTE, G., "UNAVAILABLE-TITLE UNKNOWN", BIBL.UNIV.GENEVE., 7,1860,PG.332

PLANTE, G., "LES COURANTS SECONDAIRES ET LEURS APPLICATIONS", ANN.CHIM.PHYS., 5, 1868,PG.5

PLANTE, G., "SUR L'EMPLOI DES COURANTS SECONDAIRES POUR ACCUMULER OU TRANSFORMER LES EFFECTS DE LA PILE VOLTAIQUE", C.R.HEBD.SEANCES ACAD.SCI., 74,1872,PG.592

PLANTE, G., "SUITE DE RECHERCHES SUR LES COURANTS SECONDAIRES, ET LEURS APPLICATIONS", C.R.HEBD.SEANCES ACAD.SCI., 77,1873,PG.466

PLANTE, G., "RECHERCHES SUR LES PHENOMENES PRODUITS DANS LES LIQUIDES PAR DES COURANTS ELECTRIQUES DE HAUTE TENSION", C.R.HEBD.SEANCES ACAD.SCI., 80,1875a, PG.1133

PLANTE, G., "RECHERCHES SUR LES PHENOMENES PRODUITS PAR DES COURANTS ELECTRIQUE DE HAUTE TENSION, ET SUR LEURS ANALOGIES AVEC LES PHENOMENES NATURELS", C.R.HEBD. SEANCES ACAD.SCI., 81,1875b,PG.185

PLANTE, G., "SUR LA FORMATION DE LA GRELE", C.R.HEBD.SEANCES ACAD.SCI., 81,1875c, PG.616

PLANTE, G., "SUR LA FORMATION DE LA GRELE", C.R.HEBD.SEANCES ACAD.SCI., 81, 1875d,PG.618

PLANTE, G., "UEBER EINE DEN KUGELBLITZEN ANABOGE ERSCHEINUNG", (SUMMARY), FORTSCHR.PHYS., 31,1875e,PG.913

PLANTE, G., "UEBER EINE DEN KUGELBLITZEN ANABOGE ERSCHEINUNG", ZEIT.OSTER.GES. METEOROL., 10,1875f,PG.303 (*)

PLANTE, G., "SUR LES TROMBES", C.R.HEBD.SEANCES ACAD.SCI., 82,1876a,PG.220

PLANTE, G., "SUR LA FORMATION DE LA GRELE", C.R.HEBD.SEANCES ACAD.SCI., 83,1876b, PG.314

PLANTE, G., "SUR LA FOUDRE GLOBULAIRE", C.R.HEBD.SEANCES ACAD.SCI., 83,1876c, PG.321

PLANTE, G., "ECLAIRS EN CHAPELET", C.R.HEBD.SEANCES ACAD.SCI., 83,1876d,PG.484

PLANTE, G., "UNAVAILABLE-TITLE UNKNOWN", ELEKTR.ERSCH., 1,1876e,PG.25

PLANTE, G., "ROSENKRANZFORMIGE BLITZ", (SUMMARY), FORTSCHR.PHYS., 32,1876f,PG.1216

PLANTE, G., "SUR LA FOUDRE GLOBULAIRE", (SUMMARY), FORTSCHR.PHYS., 32,1876g, PG.1216

PLANTE, G., "SUR LA FOUDRE GLOBULAIRE", MONDES, 40,1876h,PG.623 (*)

PLANTE, G., "ROSENKRANZFORMIGE BLITZ", MONDES, 40,1876i,PG.762 (*)

PLANTE, G., "ROSENKRANZFORMIGE BLITZ", NATURFORSCHER, 8,1876j,PG.424 (*)

PLANTE, G., "LUMIERE ELECTROSILICIQUE", C.R.HEBD.SEANCES ACAD.SCI., 84,1877a, PG.914

PLANTE, G., "MACHINE RHEOSTATIQUE", C.R.HEBD.SEANCES ACAD.SCI., 85,1877b,PG.294 (NBL)

PLANTE, G., "SUITE DE RECHERCHES SUR LES EFFETS PRODUITS PAR DES COURANTS ELECTRIQUES DE HAUTE TENSION, ET SUR LEURS ANALOGIES AVEC LES PHENOMENES NATURELS", C.R.HEBD.SEANCES ACAD.SCI., 85,1877c,PG.619

PLANTE, G., "MACHINE RHEOSTATIQUE", C.R.HEBD.SEANCES ACAD.SCI., 85,1877d,PG.795 (NBL)

PLANTE, G., "WANDERNDE ELEKTRISCHE FUNKEN", BEIBL.ANN.PHYS., 2,1878a,PG.620

PLANTE, G., "SUR LES EFFETS DE LA MACHINE RHEOSTATIQUE", C.R.HEBD.SEANCES ACAD. SCI., 86,1878b,PG.761 (NBL)

PLANTE, G., "ETINCELLA ELECTRIQUE AMBULANTE", C.R.HEBD.SEANCES ACAD.SCI., 87, 1878c,PG.325

PLANTE, G., "RECHERCHES SUR LE PHENOMENES PRODUITS PAR DES COURANTS ELECTRIQUE DE HAUTE TENSION, ET SUR LEURS ANALOGIES AVEC LES PHENOMENES NATURELS", C.R.HEBD. SEANCES ACAD.SCI., 88,1879a,PG.442

PLANTE, G., "RECHERCHES SUR L'ELECTRICITE", PARIS, 1879b,PG.200 (*)

PLANTE, G., "FOUDRE EN BOULE", CIEL ET TERRE, 5,1884a,PG.365

PLANTE, G., "SUR LA FOUDRE GLOBULAIRE", C.R.HEBD.SEANCES ACAD.SCI., 99,1884b,PG.273

PLANTE, G., "ON GLOBE LIGHTNING", ELECTRICIAN, 13,1884c,PG.366

PLANTE, G., "SUR LA FOUDRE GLOBULAIRE", (SUMMARY), FORTSCHR.PHYS., 40(3),1884d, PG.650

PLANTE, G., "SUR LA FOUDRE GLOBULAIRE", LA LUMIERE ELECTRIQUE, 13,1884e,PG.286 (*)

PLANTE, G., "SUR LA FOUDRE GLOBULAIRE", LA NATURE, 12(2),1884f,PG.195 (*)

PLANTE, G., "SUR LE FOUDRE GLOBULAIRE", METEOROLOGIE, 32,1884g,PG.314

PLANTE, G., "SUR LA FOUDRE GLOBULAIRE", NATURFORSCHER, 16,1884h,PG.369 (*)

PLANTE, G., "SUR LA FOUDRE GLOBULAIRE", REV.SCI., 34,1884i,PG.601 (*)

PLANTE, G., "ON GLOBE LIGHTNING", ELECTRICIAN, 14,1885a,PG.433

PLANTE, G., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ELEKTRO., 3,1885b,PG.12

PLANTE, G., "RECHERCHES SUR L'ELECTRICITE", PARIS, 1887 (*)

PLANTE, G., "LES PHENOMENES ELECTRIQUES DE L'ATMOSPHERE", PARIS, 1888,PG.60 (*)

PLANTE, G., "REPRODUCTION DU PHENOMENE DE LA FOUDRE EN BOULE", CIEL ET TERRE, 11, 1890,PG.424

PLANTE, G., "ELECTRICAL PHENOMENA IN THE ATMOSPHERE", PARIS, 1891 (*)

PLANTE, G., "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 29,1901,PG.562

POCKELS, F., "MERKWURDIGE BLITZE", METEOROL.ZEIT., 10,1893,PG.73

POCKELS, F., "EIN VERSUCH, DIE BEI BLITZSCHLAGEN ERREICHTE MAXIMALE STROMSTARKE ZU SCHATZEN", METEOROL.ZEIT., 15,1898,PG.41

POEY, M., "DES CARACTERES PHYSIQUES DES ECLAIRS EN BOULES ET DE LEURS AFFINITE AVEC L'ETAT SPHEROIDAL DE LA MATIERE", C.R.HEBD.SEANCES ACAD.SCI., 40,1855, PG.1183

POEY, M., "SUR L'ORIGINE ET LA NATURE DES ECLAIRS SANS TONNERRE ET DES TONNERRES SANS ECLAIRS", C.R.HEBD.SEANCES ACAD.SCI., 43,1856a,PG.985

POEY, M., "SUR L'ORIGINE ET LA NATURE DES ECLAIRS SANS TONNERRE ET DES TONNERRES SANS ECLAIRS", COSMOS, 9,1856b,PG.536 (*)

POITERIN, H., "EFFETS DE LA FOUDRE EN BOULE", COSMOS, 15,1859a,PG.58 (*)

POITERIN, H., "EFFETS DE LA FOUDRE EN BOULE", (SUMMARY), FORTSCHR.PHYS., 15,1859b, PG.62

POLLOCK, R.E., "NOT BALL LIGHTNING", MON.WEATHER REV., 26,1898,PG.363

POLLOG, C.H., "EIN KUGELBLITZ", METEOROL.ZEIT., 47,1930.PG.79

POLYCHRONAKIS, M.C.VEN, "REMARQUABLE COUP DE FOUDRE EN BOULE", BULL.SOC.ASTRON. FR., 22,1908,PG.479

PONNAMPERUMA, C. AND F.WELLER, "DIFFERENCES IN THE CHARACTER OF C- TO C- HYDROCARBONS FROM GASEOUS METHANE IN LOW FREQUENCY ELECTRIC DISCHARGES", NATURE, 203,1964,PG.272 (NBL)

POPOV, Y.A., "RAZRYAD MOLNII NA FYUZELYAZ SAMOLETA", PRIRODA, 48(12),1959,PG.111

POTTS, L.M., "BALL LIGHTNING", SCIENCE, 31,1910,PG.144

POUILLET, M., "COUP DE FOUDRE EXTRAORDINAIRE", C.R.HEBD.SEANCES ACAD.SCI., 35, 1852,PG.400

POULPIQUET, H., "LA FOUDRE GLOBULAIRE", LA NATURE, 17,1889a,PG.39 (*)

POULPIQUET, H., "LA FOUDRE GLOBULAIRE", METEOROLOGIE, 37,1889b,PG.72

POULPIQUET, H., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 6,1889c,PG.69

POULPIQUET, H., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 6,1889d,PG.179

POULPIQUET, H., "KUGELBLITZ", JAHRBUCH NATURWISS., 5,1889/90,PG.254

POULPIQUET, H., "GLOBULAR LIGHTNING", ELECTRICIAN, 22,1890,PG.390

POULTER, R.M., "LIGHTNING PHOTOGRAPHS", METEOROL.MAG., 70,1935,PG.289

POULTER, R.M., "PHOTOGRAPHY AND BALL LIGHTNING", WEATHER, 9,1954a,PG.121

POULTER, R.M., "BALL LIGHTNING", WEATHER, 9,1954b,PG.321

POUMIER, M., "LA FOUDRE EN BOULE", LA ASTRONOMIE, 5,1886a,PG.348 (*)

POUMIER, M., "LA FOUDRE EN BOULE", METEOROLOGIE, 34,1886b,PG.343

POWELL, J.R. AND R.DOMISH, "BALL LIGHTNING AND EXPERIMENTAL NEAR-SPHERICAL FLAMES IN DC FIELDS", BULL.AMER.PHYS.SOC., 14(11),1969,PG.1026

POWELL, J.R. AND D.FINKELSTEIN, "STRUCTURE OF BALL LIGHTNING", IN "ADVANCES IN GEOPHYSICS", H.E.LANDSBERG AND J.VAN MIEGHEM-ED., ACADEMIC PRESS, NEW YORK, 13,1969,PG.141

POWELL, J.R. AND D.FINKELSTEIN, "BALL LIGHTNING", AMERICAN SCIENTIST, 58,1970, PG.262

POWELL, J.R., D.FINKELSTEIN, M.S.ZUCKER AND J.R.MANWARING", LABORATORY PRODUCTION OF SELF-SUSTAINED ATMOSPHERIC LUMINOSITIES", AMERICAN PHYSICAL SOCIETY, 8TH ANNUAL MEETING, DIVISION OF PLASMA PHYSICS, 1966

POWELL, J.R., M.S.ZUCKER, J.F.MANWARING AND D.FINKELSTEIN, "LABORATORY PRODUCTION OF SELF-SUSTAINED ATMOSPHERIC LUMINOSITIES", BROOKHAVEN NATIONAL LABORATORY, REPORT 10625, 1965, UNPUBLISHED

POWELL, J.R., M.S.ZUCKER, J.F.MANWARING AND D.FINKELSTEIN, "LABORATORY PRODUCTION OF SELF-CONTAINED ATMOSPHERIC LUMINOSITIES", ABSTRACT 2C-2, BULL.AMER.PHYS.SOC., 12,1967,PG.751

POZWOLSKI, A.E., "THE BALL LIGHTNING", INDIAN J.METEOROL.HYDROL.GEOPHYS., 28(1), 1977,PG.74

PRATT, C.E., "BALL LIGHTNING", MARINE OBSERVER, 31,1961,PG.127

PREAUBERT, E., "NOTE SUR UN ECLAIR A PROPAGATION LENTE", METEOROLOGIE, 52,1904, PG.270

PREECE, W.H., "ON LIGHTNING AND LIGHTNING CONDUCTORS", J.SOC.TELEG.ENGR., 1,1872a, PG.333

PREECE, W.H., "LIGHTNING AND LIGHTNING CONDUCTORS-DISCUSSIONS", J.SOC.TELEG.ENGR., 1,1872b,PG.362

PRINGLE, C.S., "BALL LIGHTNING", METEOROL.MAG., 39,1904,PG.153

PRINZ, W., "ETUDE DE LA STRUCTURE DES ECLAIRS PAR LA PHOTOGRAPHIE", BULL.ACAD.ROY. BELGIQUE, III,16,1888,PG.244 (*)

PRINZ, W., "OBSERVATIONS D'ECLAIRS", CIEL ET TERRE, 26,1905/1906,PG.249

PRITT, A.T., R.D.COOMBE, D.PILIPOVICH, R.I.WAGNER, D.BENARD AND C.DYMEK, "CHEMICAL GENERATION OF A POPULATION BETWEEN THE SPIN-ORBIT STATES OF ATOMIC IODINE", APPL.PHYS.LETT., 31(11),1977,PG.745 (NBL)

PROCHNOW, O., "ERDBALL UND WELTALL", HUGO BERMUHLER VERLAG, BERLIN-LICHTERFELDE, 1928 (*)

PROCHNOW, O., "ZUR BLITZFORSCHUNG", PHYSIK.ZEIT., 31,1930a,PG.335

PROCHNOW, O., "EIN PERLENSCHNURBLITZ", ZEIT.ANGEW.METEOROL., 47,1930b,PG.316

PROHASKA, K., "EIN MERKWURDIGES ST. ELMSFEUER", JAHRBUCH DER ASTRONOMIE UND GEOPHYSIK, 3,1892,PG.326 (NBL)

PROHASKA, K., "ELMSFEUER AM SCHAFBERG", METEOROL.ZEIT., 10,1893,PG.222 (NBL)

PROHASKA, K., "BLITZSCHADEN IN STEIERMARK UND KARNTEN IM JAHRE 1899", METEOROL. ZEIT., 17,1900,PG.331

PROHASKA, K., "FEUERKUGEL IN POLLOU, STEIERMARK", METEOROL.ZEIT., 18,1901,PG.94

PROHASKA, K., "UBER BLITZSCHADEN UND BEMERKENSWERTE ENTLADUNGSFORMEN DER ATMOSPHARISCHEN ELEKTRIZITAT IM YAHR 1901", METEOROL.ZEIT., 20,1903,PG.315

PROKH, L.Z., "SHAROVAYA MOLNIYA VO VREMYA ZIMNEY GROZY V KIEV", METEOROL.I GIDROL., NO.5,1972,PG.103 (*)

PUHRINGER, A., "COMMENTS", IN "PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY", S.C.CORONITI-ED., ELSEVIER, AMSTERDAM, 1965,PG.460

PUHRINGER, A., "BEOBACHTUNG EINES KUGELBLITZES IM SALZKAMMERGUT UND EIN ERKLARUNGSVERSUCH", WETTER UND LEBEN, 19,1967,PG.57

RAAB, O., "UNAVAILABLE-TITLE UNKNOWN", BILDMESSG.UND LUFTBILDWES., 15,1940,PG.57

RAASCHE, L., "UNAVAILABLE-TITLE UNKNOWN", KORR.NATUR.VER.RIGI, 39,1896,PG.70

RACINE, E., "CURIEUX COUP DE FOUDRE", BULL.SOC.ASTRON.FR., 23,1909,PG.461

RAHIR, M.E., "CURIEUX COUP DE FOUDRE", CIEL ET TERRE, 22,1901,PG.155

RAILLARD, M., "SUR LES ECLAIRS SANS TONNERRE ET LES TONNERRES SANS ECLAIRS", C.R. HEBD.SEANCES ACAD.SCI., 43,1856a,PG.816

RAILLARD, M., "SUR LES ECLAIRS SANS TONNERRE ET LES TONNERRES SANS ECLAIRS", (SUMMARY), FORTSCHR.PHYS., 12,1856b,PG.589

RANDJELOVIC, J., "BALL LIGHTNING AND ELECTROMAGNETIC RADIATION FROM LINEAR LIGHTNING DISCHARGES", FOREIGN SCIENCE BULL., 5,NO.2,1969,PG.65

RATCLIFFE, J.A., "PHYSICS OF THE UPPER ATMOSPHERE", ACADEMIC PRESS, NEW YORK, 1960 (NBL)

RAYLE, W.D., "BALL LIGHTNING CHARACTERISTICS", NASA TECH.NOTE, NASA-TN-D-3188,1966

RAYMOND, G., "UN COUP DE FOUDRE REMARQUABLE", LA NATURE, MARSH,1887a,PG.227 (*)

RAYMOND, G., "UN COUP DE FOUDRE REMARQUABLE", METEOROLOGIE, 35,1887b,PG.221

REICHENBACH, E., "METEOROLOGISCHE NOTIZEN UND KORRESPONDENZEN", ZEIT.ANGEW. METEOROL., 6,1889,PG.119

REID, W., "AN ATTEMPT TO DEVELOP THE LAWS OF STORMS", LONDON, 1838,PG.402 (*)

REIMANN, D., "BEOBACHTUNG VON KUGELBLITZEN ZU HIRSCHBERG IN SCHLEISIEN", (SUMMARY), FORTSCHR.PHYS., 42(3),1886a,PG.654

REIMANN, D., "BEOBACHTUNG VON KUGELBLITZEN ZU HIRSCHBERG I. SCHL.", METEOROL. ZEIT., 3,1886b,PG.510

REIMANN, D., "WEITERE BERICHTE UBER GEWITTERERSCHEINUNGEN IM SCHLESISCHE GEBIRGE", METEOROL.ZEIT., 4,1887,PG.164

REIMANN, D., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 13,1896,PG.25 (*)

REIMANN, D., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 14,1897a,PG.167 (*)

REIMANN, D., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 14,1897b,PG.263 (*)

REIMANN, D., "EIN VOM WIND BEWEGTER BLITZ", METEOROL.ZEIT., 22,1905,PG.360

REINERS, F., "AUS DEN REISENBERICHTEN DES KAPT. R.REINERS VON DER DEUTSCHEN BARK 'AEOLUS', 1. KUGELBLITZ", ANN.HYDRO.MARIT.METEOROL., 10,1882a,PG.582

REINERS, F., "KUGELBLITZ", (SUMMARY), FORTSCHR,PHYS., 38(3),1882b,PG.544

REISCH-PERKALLEN, H., "EIGENTHUMLICHE ELEKRISCHE ERSCHEINUNG", ZEIT.ANGEW. METEOROL., 13,1896,PG.143 (*)

REMSCHEID, M., "UNAVAILABLE-TITLE UNKNOWN", UMSCHAU, 18,1907,PG.576 (*)

RENDORF, O., "ATMOSFERNOYE ELEKTRICHESTVO", LENINGRAD, 1934 (*)

RENOU, E., "SUR QUELQUES PARTICULAIRES DE LA FOUDRE", C.R.HEBD.SEANCES ACAD.SCI., 83,1876,PG.1002

REYNOLDS, W.C., "GLOBULAR LIGHTNING", NATURE, 112,1923,PG.903

REYNOLDS, W.C., "GLOBULAR LIGHTNING", NATURE, 125,1930,PG.413

REYNOLDS, W.C., "CHARGED AEROSOLS AND BALL LIGHTNING", NATURE, 128,1931,PG.584

RHIGHI, M., "LA FOUDRE GLOBULAIRE", LE COSMOS, JUIN,1896a,PG.353 (*)

RHIGHI, M., "LA FOUDRE GLOBULAIRE", METEOROLOGIE, 44,1896b,PG.116

RICHTER, P., "GEWITTER", ZEIT.ANGEW.METEOROL., 29,1912,PG.233 (*)

RICHTER, P., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 30,1913,PG.21

RICHTER, P., "KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 70(3),1914a,PG.230

RICHTER, P., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 31,1914b,PG.215

RIECKE, E., "UNAVAILABLE-TITLE UNKNOWN", GOTTING.NACHR., 1895,PG.41&

RIGGENBACH-BURCKHARDT, A., "PERLSCHNUR-BLITZ", METEOROL.ZEIT., 14,1897,PG.62

RIGHI, A., "SULLE SCINTILLE COSTITUITE DA MASSE LUMINOSE IN MOTO", ATTI.D.ROM. ACCAD.LINCEI, REND., IV,7,1891a,PG.330 (*)

RIGHI, A., "UNAVAILABLE-TITLE UNKNOWN", LA LUMIERE ELECTRIQUE, 13,1891b,PG.47

RIGHI, A., "UNAVAILABLE-TITLE UNKNOWN", LA LUMIERE ELECTRIQUE, 13,1891c,PG.501

RIGHI, A., "UNAVAILABLE-TITLE UNKNOWN", LA LUMIERE ELECTRIQUE, 13,1891d,PG.604

RIGHI, A., "SOPRA UNA SPECIE DI SCINTILLE ELETTRICHE NELLE QUALI LA LUMINOSITA SI PROPAGA GRADATAMENTE DA UN ELETTRODO ALL ALTRO", MEM.R.ACCAD.SCI.IST.BOLOGNA, 1, 1891e,PG.315 (*)

RIGHI, A., "RICERCHE SPERIMENTALI INTORNO A CERTE SCINTILLE ELETTRICHE COSTITUITE DA MASSE LUMINOSE IN MOTO", MEM.R.ACCAD.SCI.IST.BOLOGNA, V,1,1891f,PG.679 (*)

RIGHI, A., "UNAVAILABLE-TITLE UNKNOWN", MEM.R.ACCAD.SCI.IST.BOLOGNA, 2,1892,PG.379

RIGHI, A., "UNAVAILABLE-TITLE UNKNOWN", MEM.R.ACCAD.SCI.IST.BOLOGNA, 5,1895,PG.445

RIGHI, A., "UNAVAILABLE-TITLE UNKNOWN", ECLAIRAGE ELECTRIQUE, 1896a

RIGHI, A., "NACHAHUNG VON KUGELBLITZEN", (SUMMARY), FORTSCHR.PHYS., 52(3),1896b, PG.300

RIGHI, A., "NACHAHUNG VON KUGELBLITZEN", PROMETHEUS, 7,1896c,PG.687 (*)

RIGHI, A., "NACHAHUNG VON KUGELBLITZEN", REV.SCI., 6 JUNI 1896d (*)

RIGOLLET, C., "METEOROLOGIE-L'ECLAIR EN BOULE", BULL.SOC.ASTRON.FR., 19,1905, PG.267

RIHANEK, M., M.LADISLAV AND J.POSTRANECKY, "UNAVAILABLE-TITLE UNKNOWN", NAKLAD. CESKOS.ADAD.VED., 1957,PG.90,463

RITCHIE, D.J., "RED LIGHTNING-ARE THE SOVIETS USING BALL LIGHTNING AS AN ANTI- MISSILE WEAPON?", BENDIX AVIATION CORP., RESEARCH LAB DIV., DATA SHEET, AUG- SEPT.,1959a (*)

RITCHIE, D.J., "REDS MAY USE LIGHTNING AS WEAPON", MISSILES AND ROCKETS, AUGUST 24 1959, 5,1959b,PG.13

RITCHIE, D.J., "BALL LIGHTNING - A COLLECTION OF SOVIET RESEARCH IN ENGLISH TRANSLATION", CONSULTANTS BUREAU, NEW YORK, 1961

RITCHIE, D.J., "BALL LIGHTNING IN NATURE AND IN THE LABORATORY", INST.ELECTR. ENGR.J.(LONDON), 9,1963,PG.202

RITCHIE, D.J. AND B.G.SOUTHWARD-EDITORS, "THE NATURE OF BALL LIGHTNING", PLENUM PRESS, NEW YORK, 1964

RIVE, A.DE, "TRAITE D'ELECTRICITE THEORIQUE ET APPLIQUEE", PARIS, 3,1858,PG.197

ROBERT, A., "NOTE SUR UN PHENOMENE LUMINEUX", METEOROLOGIE, 57,1909,PG.296

ROCHE, M., "OBSERVATIONS SUR LA FOUDRE EN BOULE TOMBEE A AUTUN LE 16 JUILLET", C.R.HEBD.SEANCES.ACAD.SCI., 139,1904,PG.465

ROCHE, M., "WIRKUNGEN EINES KUGELBLITZES", JAHRBUCH DER ASTRONOMIE UND GEOPHYSIK, 16,1905,PG.346

RODNEY, P.F. AND D.R.TOMPKINS, "A THEORY OF BALL LIGHTNING", BULL.AMER.PHYS.SOC., 20,1975,PG.659

RODEWALD, M., "KUGELBLITZBEOBACHTUNGEN", ZEIT.METEOROL., 8,1954,PG.27

ROOD, O.N., "ON THE NATURE AND DURATION OF THE DISCHARGE OF A LEYDEN JAR CONNECTED WITH AN INDUCTION COIL", AMER.J.SCI., 48,1869,PG.153

ROOD, O.N., "OBSERVATIONS ON THE DURATION AND MULTIPLE CHARACTER OF FLASHES OF LIGHTNING", AMER.J.SCI.ARTS, 105,1873,PG.163

ROSSMAN, M., "ST. ELMSFEUER-BEOBACHTUNGEN", ZEIT.ANGEW.METEOROL., 44,1927, PG.262 (NBL)

ROSSMANN, F., "BLITZBEOBACHTUNGEN: WOLKEN- UND ERDBLITZ, LINIEN- UND PERLSCHNUR- BLITZ", METEOROL.ZEIT., 56,1939a,PG.194

ROSSMANN, F., "BLITZ UND HAGEL (UBER DIE ELEKTRISCHE NATUR DES GEWITTERS)", METEOROL.ZEIT., 56,1939b,PG.372

ROSSMAN, F., "UBER DEN KUGELBLITZ", WETTER UND KLIMA, 2,1949,PG.75

ROTCH, L., "METEOROLOGIE-ECLAIR EN BOULE DANS LA TOUR EIFEL", BULL.SOC.ASTRON.FR., 17,1903a,PG.483

ROTCH, L., "ECLAIR EN BOULE OBSERVE' A PARIS", CIEL ET TERRE, 24,1903b,PG.544

ROTCH, L., "ECLAIR EN BOULE OBSERVE A PARIS", METEOROLOGIE, 51,1903c,PG.205

ROTH, F., "BEOBACHTUNG DES BLITZES DURCH EINEN VON DEMSELBEN GETROFFENEN", METEOROL.ZEIT., 6,1889,PG.231

ROUSSELOT, U., "FOUDRE EN BOULE EXTRAORDINAIRE", BULL.SOC.ASTRON.FR., 18,1904, PG.510

ROZEMA, M., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 65,1951,PG.55

ROZZI, N., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 25,1911,PG.260

RUDSKI, D., "GEWITTER UND KUGELBLITZ IN KRAKAU", METEOROL.ZEIT., 22,1905,PG.284

RUMEKER, G.A.L., "BLITZPHOTOGRAPHIE", METEOROL.ZEIT., 16,1899,PG.422

RUSSELL, A., "BALL LIGHTNING", NATURE, 126,1930,PG.809

RUSSELL, A.E., "BALL LIGHTNING", MON.WEATHER REV., 33,1905,PG.409

RUSSELL, S.C., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 18,1904a,PG.509

RUSSELL, S.C., "BALL LIGHTNING", METEOROL.MAG., 39,1904b,PG.153

RUTGERS, G.A.W., "EIN KUGELBLITZ?", PHYS.BLATTER, 14,1958,PG.417

RUTHERFORD, E.C., "THE THUNDERSTORM OF JULY 22ND, 1924 (AT WOKING)", METEOROL. MAG., 59,1925,PG.153

RYAN, G.M., "FOUDRE GLOBULAIRE", LE COSMOS, 32,1895a,PG.191 (*)

RYAN, G.M., "FOUDRE GLOBULAIRE", METEOROLOGIE, 43,1895b,PG.303

RYAN, G.M., "NOTE", NATURE, 52,1895c,PG.394

RYAN, G.M., "LES CAPRICES DE LA FOUDRE. FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 11, 1897a,PG.300

RYAN, G.M., "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 46,1897b,PG.95

SACC, M., "SUR EN COUP DE FOUDRE QUI A FRAPPE LE TELEGRAPHE ELECTRIQUE ENTRE MONTELIMART ET LYON", C.R.HEBD.SEANCES ACAD.SCI., 53,1861,PG.646

SAGAN, C. AND T.PAGE-EDITORS, "UFO'S, A SCIENTIFIC DEBATE", CORNELL UNIVERSITY PRESS, ITHACA, NEW YORK, 1972

SALANAVE, L.E., "DISCUSSIONS", IN "PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY", S.C.CORONITI-ED, ELSEVIER, AMSTERDAM, 1965, PG.464

SAUTER, F., "UEBER KUGELBLITZ, I. THEIL: THEORIE DER KUGELBLITZE", (SUMMARY), FORTSCHR.PHYS., 46(3),1890,PG.423

SAUTER, F., "UEBER KUGELBLITZ, II. THEIL: BEISPIELE.VON KUGELBLITZEN", (SUMMARY), FORTSCHR.PHYS., 48(3),1892a,PG.367

SAUTER, F., "BEISPIELE DER KUGELBLITZE", PROGRAMME DES KGL.REAL-GYMNASIUMS IN ULM ZUM SCHLUSSE DE SCHULJAHRES (1891/1892), ULM,1892b,PG.20 (*)

SAUTER, F., "UEBER KUGELBLITZ, II. THEIL: BEISPIELE VON KUGELBLITZEN", PROMETHEUS, 5,1892c,PG.481 (*)

SAUTER, F., "DER KUGELBLITZ", JAHRBUCH DER ASTRONOMIE UND GEOPHYSIK, 4,1893,PG.314

SAUTER, F., "UEBER KUGELBLITZE", METEOROL.ZEIT., 12,1895,PG.241

SAUTER, F., "UEBER KUGELBLITZ", SAMMLUNG GEMEINVERSTANDLICHER WISSENSCHAFTLICHER VORTRAGE, SER.2, 9,1896,PG.121

SAUTER, F., "UEBER KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 53(3),1897a,PG.313

SAUTER, F., "UEBER KUGELBLITZ", NATURWISS.RUND., 12,1897b,PG.217 (*)

SAUTER, F., "UEBER KUGELBLITZ", METEOROLOGIE, 46,1898,PG.101

SCHEMINZKY, F. AND F.WOLF, "PHOTOGRAPHIE EINES PERLSCHNURBLITZES", SITZUNG.AKAD. WISS.WIEN, MATH.-NATURWISS.KLASSE, IIA,156(1/2),1948,PG.1

SCHEURER, F., "OBSERVATIONS DE FOUDRE GLOBULAIRE", LA METEOROLOGIE, 7,1931, PG.249 (*)

SCHIODT, F.VON, "KUGLELQUET", (SUMMARY), FORTSCHR.PHYS., 49(3),1893a,PG.384

SCHIODT, F.VON, "KEGLELYNET", TIDSSKRIFT FOR PHYSIK OG CHEMI, III,2,1893b, PG.242 (*)

SCHLOER, H., "UNAVAILABLE-TITLE UNKNOWN", NATUR UND KULTUR, 45,1953,PG.242

SCHLOHBOHM, K.A., "BLITZSCHLAG UND KUGELBLITZ", METEOROL.RUND., 14,1961,PG.93

SCHMAUSS, A., "PERLSCHNURBLITZ", PHYS.ZEIT., 10,1909,PG.968

SCHMAUSS, A., "PERLSCHNURBLITZ", METEOROL.ZEIT., 27,1910,PG.83

SCHMAUSS, A., "RANDBERMERKUNGEN I.", METEOROL.ZEIT., 35,1918,PG.181

SCHMAUSS, A., "KUGELBLITZ?", ZEIT.ANGEW.METEOROL., 57,1940,PG.238 (*)

SCHMIDT, E.E., "UNAVAILABLE-TITLE UNKNOWN", LEHRBUCH METEOROL., 1860,PG.781 (*)

SCHMIDT, K.E.F., "UNAVAILABLE-TITLE UNKNOWN", ELEKTRO.ZEIT., 26,1905,PG.903

SCHNEIDER, E., "TONNERRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 119,1894,PG.506

SCHNEIDERMANN, K., "BLITZAUFNAGMEN VON LINIEN-UND KUGELBLITZ", FEUER-WEHR-VERBANDS -ZEITUNG, 44(1),1934,PG.1

SCHNEIDERMUHL, M., "BEOBACHTUNG VON KUGELBLITZ", METEOROL.ZEIT., 38,1921,PG.183

SCHONERT, H., "AUFTRETEN EINES KUGELBLITZES IN HERINGSDORF", ZEIT.METEOROL., 17,1965,PG.61

SCHONLAND, B.F.J., "THE FLIGHT OF THE THUNDERBOLTS", OXFORD UNIV.PRESS, LONDON, 1950

SCHONLAND, B.F.J., "THE LIGHTNING DISCHARGE", HANDBUCH DER PHYSIK, BERLIN, 22, 1956,PG.576

SCHONLAND, B.F.J., "LIGHTNING AND THE LONG ELELCTRIC SPARK", ADVANCEMENT OF SCIENCE, 19,1962a,PG.306

SCHONLAND, B.F.J., "LIGHTNING AND THE LONG ELECTRIC SPARK", NATURE, 195,1962b, PG.880

SCHOUTE, C., "THE TERM FIREBALL", METEOROL.MAG., 61,1926,PG.238

SCHRADE, M.VON, "AUFTRETEN EINES KUGELBLITZES IN HERINGSDORF", ZEIT.METEOROL., 17,1962,PG.61

SCHRAMMEN, M., "FOUDRE EN BOULE", CIEL ET TERRE, 11,1890,PG.348

SCHREIBER, D., "BEITRAGE ZUR HAGELTHEORIE", METEOROL.ZEIT., 18,1901,PG.58

SCHROTH, H., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 57,1940.PG.306

SCHROTH, H., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 59,1942,PG.200

SCHULTZE, H.S., AND H.REITZ, "KUGELBLITZ", PROMETHEUS, 18,1907,PG.416 (*)

SCHUMANN, G.A., "UNAVAILABLE-TITLE UNKNOWN", PROG.GYMN.QUEDLINBERG, 1848,PG.28

SCHUSTER, A., "L'ELECTRICITE ATMOSPHERIQUE", CIEL ET TERRE, 17,1896a,PG.318

SCHUSTER, A., "L'ELECTRICITE ATMOSPHERIQUE", CIEL ET TERRE, 17,1896b,PG.441

SCHUSTER, A., "L'ELECTRICITE ATMOSPHERIQUE", CIEL ET TERRE, 17,1896c,PG.462

SCHUSTER, A., "ATMOSPHERIC ELECTRICITY", (SUMMARY), FORTSCHR.PHYS., 52(3),1896d, PG.286

SCHUSTER, A., "ATMOSPHARISCHE ELEKTRIZITAT", METEOROL.ZEIT., 13,1896e,PG.215

SCHUSTER, A., "ATMOSPHERIC ELECTRICITY", NATURE, 53,1896f,PG.207

SCHUSTER, A., "ATMOSPHERIC ELECTRICITY", NATURWISS.RUND., 11,1896g,PG.133 (*)

SCHUSTER, A., "ATMOSPHERIC ELECTRICITY", NATURWISS.RUND., 11,1896h,PG.145 (*)

SCHWEGLER, H., "UBER DER KUGELBLITZ", NATURWISS.RUND., 4,1951,PG.169

SCOTT, E.K., "UNAVAILABLE-TITLE UNKNOWN", LETTER TO YORKSHIRE POST, 20 OCT.1923a

SCOTT, E.K., GLOBULAR LIGHTNING , NATURE, 112,1923b,PG.760

SCOTT, J.R., "PHOTOGRAPHY AND BALL LIGHTNING", WEATHER, 10,1955,PG.98

SCOTT, M., "NEWSPAPER ACCOUNTS", FROM M.MICHELSKI, "CURIOUS PHENOMENON DURING THE GALE", IN LONDON DAILY PAPERS, OCT. 12, 1877; ROY.METEOROL.SOC.Q.J., 4,1878a, PG.167

SCOTT, M., "NEWSPAPER ACCOUNTS", FROM M.MICHELSKI, "SINGULAR PHENOMENON AT LOWER CUMBER" IN LONDONDERRY SENTINEL, JUNE 1, 1878; ROY.METEOROL.SOC.Q.J., 4,1878b, PG.167

SEIGNER, R., "PERLSCHNURBLITZ", WETTER UND LEBEN, 18,1966,PG.54

SELIGER, H.H., J.B.BUCK, W.G.FASTIE AND W.D.MCELROY, "THE SPECTRAL DISTRIBUTION OF THE FIREFLY LIGHT", J.GEN.PHYSIOLOGY, 48(1),1964,PG.95 (NBL)

SELIGER, H.H. AND R.A.MORTON, "A PHYSICAL APPROACH TO BIOLUMINESCENCE", IN "PHOTOPHYSIOLOGY", VOL. IV, CHAP.13,1968,PG.253 (NBL)

SEQUIER, M., "GLOBE DE FEU", C.R.HEBD.SEANCES ACAD.SCI., 34,1852,PG.871

SESTIER, F., "DE LA FOUDRE, DE SES FORMES ET DE SES EFFETS", PARIS, BALLIERE ET FILS, 1,1866,PG.7 AND 119 (*)

SEYBOTH, R., "BALL LIGHTNING AT SEA", SCIENTIFIC AMERICAN, 86,1902,PG.36

SHAFRANOV, V.D., "ON MAGNETOHYDRODYNAMICAL EQUILIBRIUM CONFIGURATIONS", SOV.PHYS. JETP, 6,1957,PG.545, TRANSLATION OF ZH.EXSP.TEOR.FIZ,SSSR, 33,1957,PG.710

SHAFRANOV, V.D., "ON MAGNETOHYDRODYNAMICAL EQUILIBRIUM CONFIGURATIONS", IN "BALL LIGHTNING", D.J.RITCHIE-ED, CONSULTANTS BUREAU, NEW YORK, 1961

SHAGIN, I., "BALL LIGHTNING PHOTOGRAPH", OGONEK, 20,1960,PG.34

SHAPIRO, A.R. AND W.K.R.WATSON, "THREE DIMENSIONAL CONTAINMENT OF CHARGED PARTICLES BY ORTHOGONAL STANDING WAVES", PHYS.REV., 131,1963,PG.495 (NBL)

SHAPIRO, M.L., "SHEDDING LIGHT ON UFO'S", OPTICAL SPECTRA, 13(4),1979,PG.13

SHAW, N. AND E.AUSTIN, "MANUAL OF METEOROLOGY", CAMBRIDGE UNIVERSITY PRESS, VOL.1, 1926,PG.247 AND VOL.3,PG.393

SHIPLEY, J.F., "LIGHTNING AND ITS SYMBOLS", ROY.METEOROL.SOC.Q.J., 67,1941,PG.135

SHUNAMAN, F., "12-MILLION VOLTS", RADIO ELECTRONICS, 47(6),1976,PG.32

SIE, N., "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 32,1895,PG.191

SIEBERG, A., "UNAVAILABLE-TITLE UNKNOWN", ERDBEBENKUNDE-JENA, 1923 (*)

SILBERG, P.A., "ON THE QUESTION OF BALL LIGHTNING", INTERNAL REPORT, RAYTHEON COMPANY, WALTHAM,MASS.,1961a

SILBERG, P.A., "ON THE QUESTION OF BALL LIGHTNING", J.APPL.PHYS., 32,1961b,PG.30

SILBERG, P.A., "BALL LIGHTNING AND PLASMOIDS", J.GEOPHYS.RES., 67,1962,PG.4941

SILBERG, P.A., "INVESTIGATION OF THE GENERATION AND PROPAGATION OF HIGH-ENERGY SPHERICAL PLASMOIDS", AERONAUTICAL SYSTEMS DIVISION, USAF, ASD-TECH.DOCUMENT, REPORT NO.ASD-TDR-63-47, OCT.1963

SILBERG, P.A., "A STANDING-WAVE DISCHARGE IN AIR", J.APPL.PHYS., 35,1964, PG.2264 (NBL)

SILBERG, P.A., "A REVIEW OF BALL LIGHTNING", IN "PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY", S.C.CORONITI-ED., ELSEVIER, AMSTERDAM, 1965,PG.436

SILBERG, P.A., "A NOTE ON THE FORMATION OF THE FIREBALL PLASMA", J.APPL.PHYS., 49(3),1978,PG.1110

SIMON, K.H., "DER RATSELHAFTE KUGELBLITZ", NATURWISS.RUND., 16,1963,PG.450

SIMPSON, G.C., "NATURE AND CAUSE OF BALL LIGHTNING", MON.WEATHER REV., 44,1916, PG.121

SIMPSON, G.C., "THUNDERSTORMS AND GLOBULAR LIGHTNING", NATURE, 112,1923,PG.727

SIMPSON, G.C., "BALL LIGHTNING", NATURE, 113,1924,PG.677

SINGER, S., "THE UNSOLVED PROBLEM OF BALL LIGHTNING", NATURE, 198,1963,PG.745

SINGER, S., "UNSOLVED PROBLEMS OF BALL LIGHTNING", IN "PROBLEMS OF ATMOSPHERIC AND SPACE ELECTRICITY", S.C.CORONITI-ED., ELSEVIER, AMSTERDAM, 1965,PG.461

SINGER, S., "UNKNOWN THINGS IN THE SKY", ASTRONAUTICS AND AERONAUTICS J., 6(12), 1968,PG.12

SINGER, S., "THE NATURE OF BALL LIGHTNING", PLENUM PRESS, NEW YORK, 1971

SINGER, S., "BALL LIGHTNING", IN "LIGHTNING", R.H.GOLDE-ED., ACADEMIC PRESS, 1,1977,PG.409

SINITSYN, V.I., "PROPERTIES OF A LOW PRESSURE SPHERICAL DISCHARGE", SOV.PHYS.TECH. PHYS., 22(5),1977a,PG.576

SINITSYN, V.I., "O NEKOTORYKH SVOISTVAKH SFERICHESKOGO RAZRIADA PRI PONIZHENNOM DAVLENII", ZH.TEKH.FIZ., 47,1977b,PG.966

SKOWRONEK, M., "DECHARGE FILIFORME EMISE PAR UNE POINTE FINE PORTEE A HAUT TENSION POSITIVE PAR RAPPORT A UN PLAN", C.R.HEBD.SEANCES ACAD.SCI., 250,1960,PG.1808 (NBL)

SMIRNOV, B.M., "ANALYSIS OF THE NATURE OF BALL LIGHTNING", SOV.PHYS.USP., 18, 1975a,PG.636, TRANSLATION OF USP.FIZ.NAUK., 116,1975,PG.731

SMIRNOV, B.M., "OB ANALIZE PRIRODY SHAROVOI MOLNII", USP.FIZ.NAUK, 116,1975b, PG.731

SMIRNOV, B.M., "VOZNIKNOVENIE SHAROVOI MOLNII", DOKL.AKAD.NAUK.SSSR, 226,1976a, PG.806

SMIRNOV, B.M., "FORMATION OF BALL LIGHTNING", SOV.PHYS.-DOKL., 21(2),1976b,PG.89, TRANSLATION OF DOKL.AKAD.NAUK.SSSR, 26,1976,PG.806

SMIRNOV, B.M., "BALL-LIGHTNING MODEL", SOV.PHYS.TECH.PHYS., 22(4),1977a,PG.488, ENGLISH TRANSLATION OF ZH.TEKH.FIZ., 47,1977,PG.814

SMIRNOV, B.M., "PROTSESSY V SHAROVOI MOLNII", ZH.TEHK.FIZ., 47,1977b,PG.814

SMITH, B.W., "REMARKABLE FORM OF LIGHTNING", NATURE, 18,1878,PG.302

SMITH, P., "SINGULAR EFFECT OF LIGHTNING", J.FRANKLIN INSTITUTE, 70,1860,PG.54

SMITH, W.F., "BALL LIGHTNING", (SUMMARY), FORTSCHR.PHYS., 36(3),1880a,PG.360

SMITH, W.F., "BALL LIGHTNING", NATURE, 22,1880b,PG.267

SMITH, W.G., "LIGHTNING", NATURE, 30,1884,PG.241

SMITH-GORDON, L., "BALL LIGHTNING", METEOROL.MAG., 57,1923,PG.336

SNIGIER, P., "FUSION ENERGY-WILL EXPERIMENTS IN BALL LIGHTNING

PROVIDE THE KEY?", ELECTRONIC DESIGN NEWS, APRIL 20,1976,PG.17

SNOW-HARRIS, W., "ON THE NATURE OF THUNDERSTORMS", J.W.PARKER, LONDON, 1843,PG.36

SOUBBOTINE, N.DE, "METEOROLOGIE - CAS EXTRAORDINAIRE DE FOUDRE EN BOULE", BULL. SOC.ASTRON.FR., 15,1901,PG.476

SOUBBOTINE, N.DE, "CAS DE FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 16,1902,PG.117

SOUCAZE, A., "LA DESCRIPTION DES EFFETS PRODUITS PAR UN COUP DE FOUDRE, A CAMPAN, LE 24 JUILLET DERNIER", C.R.HEBD.SEANCES ACAD.SCI., 99,1884a,PG.262

SOUCAZE, A., "EFFETS PRODUITS PAR UN COUP DE FOUDRE A CAMPAN LE 24 JOUILLET", (SUMMARY), FORTSCHR.PHYS., 40(3),1884b,PG.656

SOURDILLON, M., "ETUDE A LA CHAMBRE DE BOYS DE L'ECLAIR DAN L'AIR ET DU COUP DE FOUDRE A CIME HORIZONTAL", ANN.GEOPHYSIQUE, 8,1952,PG.349

SPITZER, L., JR., "PHYSICS OF FULLY IONIZED GASES", INTERSCIENCE, NEW YORK, 1962 (NBL)

SPRAGUE, J.T., "ELECTRICITY", LONDON, 1875 (*)

STADE, H., "KUGELBLITZ", METEOROL.ZEIT., 38,1921,PG.314

STAKHANOV, I.P., "CONCERNING THE NATURE OF BALL LIGHTNING", JETP LETT., 18,1974, PG.114, TRANSLATION FROM ZH.ETF.TEOR.FIZ., 18,1973,PG.193

STAKHANOV, I.P., "STABILITY OF BALL LIGHTNING", SOV.PHYS.-TECH.PHYS., 19,1975, PG.861, TRANSLATION OF ZH.TEKH.FIZ., 44,1974,PG.1373

STAKHANOV, I.P., "CLUSTER PLASMA AND RADIATION FROM BALL LIGHTNING", SOV.PHYS. TECH.PHYS., 21(1),1976,PG.44 , TRANSLATION OF "KLASTERNAYA PLAZMA I ILLUCHENIE SHAROVOI MOLNII", ZH.TEKH.FIZ., 46(1),1976,PG.82

STANDLER, R.B., "HOW TO REPORT BALL LIGHTNING", WEATHERWISE, 25,1972,PG.186

STEADWORTHY, M.A., "LES MYSTERES DE LA FOUDRE", BULL.SOC.ASTRON.FR., 31,1917,PG.19 PG.197 (NBL)

STEINHEIM, M., "COUP DE TONNERRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 36,1853, PG.744

STEKOL'NIKOV, I.S., "FIZIKA MOLNII I GROZOZASNITA", (THE PHYSICS OF THUNDER AND LIGHTNING PROTECTION), IZD. AN-SSSR, MOSCOW-LENINGRAD, 1943,PG.145 (*)

STEKOL'NIKOV, I.S., "IZUCHENIYE MOLNII GROZOZASHCHITY" (STUDIES OF LIGHTNING AND LIGHTNING PROTECTION), AS-USSR PRESS, 1955 (*)

STEKOL'NIKOV, I.S., "PRIRODA DLINNOY ISKRY", MOSCOW-LENINGRAD, 1960 (*)

STENHOFF, M., "BALL LIGHTNING", NATURE, 260,1976,PG.596

STOKES, G.G., "LETTERS TO THE EDITOR", NATURE, 61,1900,PG.343

STOLTERFOTH, M.H., "ECLAIR EN REBAN BOUCLE", BULL.SOC.ASTRON.FR., 13,1899,PG.45

STRANZ, H., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 57,1940,PG.306

STRANZ, H., "EIN FRONTGEWITTER MIT KUGELBLITZ", ZEIT.ANGEW.METEOROL., 59,1942, PG.200 (*)

STRICKLAND, J., "UNAVAILABLE-TITLE UNKNOWN", ENGLISH MECH., 2,1845,PG.125

STOHR, A., "KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 68(3),1912a,PG.311

STOHR, A., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 29,1912b,PG.188 (*)

STROMEYER, C.E., "REMARKABLE LIGHTNING FLASHES", NATURE, 60,1899,PG.520

STUCK, E., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 14,1897,PG.214 (*)

STUDER, J., "UNAVAILABLE-TITLE UNKNOWN", ANN.SCHWEIZER.METEOROL.CENT.AUST., 22, 1885,APPENDIX 3 (*)

STUNDER, J., "ELEKTRISCHE ERSCHEINUNGEN AM SANTIS 28.JUNI 1885 WAHREND EINES HEFTIGEN GEWITTERS", JAHRB.SCHWEIZER ALPEN-CLUB, 1885/86 (*)

STUNDER, J., "ELEKTRISCHE ERSCHEINUNGEN AM SANTIS 28.JUNI 1885 WAHREND EINES HEFTIGEN GEWITTERS", (SUMMARY), FORTSCHR.PHYS., 42(3),1886a,PG.673

STUNDER, J., "ELEKTRISCHE ERSCHEINUNGEN AM SANTIS 28.JUNI 1885 WAHREND EINES HEFTIGEN GEWITTERS", OESTERS.TOUR.ZTG., 1886b,PG.211 (*)

STUNDER, P., "BEMERKENSWERTHE BLITZSCHLAGE", METEOROL.ZEIT., 5,1888,PG.158

STUNDER, P., "BEMERKENSWERTHE BLITZSCHLAGE", METEOROLOGIE, 37,1889,PG.167

SUBRAMANIAM, A.H., "BALL LIGHTNING AT MADRAS ON 20 OCTOBER 1962", IND.J.METEOROL. AND GEOPHYS., 14,1962,PG.358

SULLIVAN, W., "BALL LIGHTNING STUDIES", WEATHERWISE, 28,1975,PG.220

SURING, R., "MERKWURDIGE BLITZWIRKUNG", METEOROL.ZEIT., 31,1914,PG.90

SVIATSKY, D., "METEOROLOGIE-LES FEUX SAINT-ELME EN RUSSIA", BULL.SOC.ASTRON.FR., 15,1901,PG.476 (NBL)

SWAIN, W., "ANOTHER CASE OF BALL LIGHTNING", ROY.ASTRON.SOC.CANADA, 27,1933,PG.254

SWART, C.D., "RARE ELECTRICAL PHENOMENON AT SEA", MONTHLY WEATHER REV., 15,1887, PG.84 (*)

SWART, C.D., "RARE ELECTRICAL PHENOMENON AT SEA", AMER.J.METEOROL., 4,1888,PG.98

SWINHOE, P., "BALL LIGHTNING", J.METEOROL., 3(31),1978,PG.216

SYMONS, G., "UNAVAILABLE-TITLE UNKNOWN", J.SOC.TEL.ENGR., 1,1872,PG.376

SYMONS, M., "DISCUSSIONS ON WATER SPOUTS AND GLOBULAR LIGHTNING", ROY.METEOROL. SOC.Q.J., 4,1878,PG.165

SZPOR, S., "ECLAIR GLOBULAIRE, ECLAIR EN CHAPELET, NOUVELLE THEORIE", ACTA GEOPHYS.POL., 25(4),1977,PG.327

TAIT, C., "FIREBALLS AT SEA", SCIENTIFIC AMERICAN, 73,1895,PG.405

TAIT, J.B., "BOLBLIKSEM TE WARNSVELD OP 28 NOVEMBER 1951", (BALL LIGHTNING AT WARNSVELD ON 28 NOVEMBER 1951), HAMEL EN DAMPRING, 50(718),1952,PG.134 (*)

TAIT, P.G., "THUNDERSTORMS", NATURE, 22,1880a,PG.339

TAIT, P.G., "THUNDERSTORMS", NATURE, 22,1880b,PG.364

TAIT, P.G., "THUNDERSTORMS", NATURE, 22,1880c,PG.408

TAIT, P.G., "THUNDERSTORMS", NATURE, 22,1880d,PG.436

TAIT, P.G., "THUNDERSTORMS", ELECTRICIAN, 13,1884,PG.114

TAIT, P.G., "THUNDERSTORMS", IN "LIFE AND SCIENTIFIC WORK OF PETER GUTHRIE TAIT" BY C.G.KNOTT, CAMBRIDGE UNIVERSITY PRESS, SUPPLEMENT, 1911, PG.312

TAKER, L.J., "FLYING SAUCERS AND THE USAF", VAN NOSTRAND PUBL., PRINCETON,N.J., 1960

TALMAN, C.F., "BALL LIGHTNING", AMERICAN MERCURY, 26,1932,PG.69

TAMURA, Y., "AN ANALYSIS OF ELECTRIC FIELD AFTER LIGHTNING DISCHARGE", J.GEOMAG. AND GEOELECT., 6,1954,PG.34

TANENBAUM, B.S., "PLASMA PHYSICS", MCGRAW HILL, NEW YORK, CHAPTER 2,1967 (NBL)

TANTOR, T.L., "GLOBULAR DISCHARGE OF LIGHTNING", ROY.ASTRON.SOC.CANADA J., 12, 1913,PG.530

TARDY, M., "ECLAIRS EN BOULE", LE COSMOS, AOUT,1891a,PG.73 (*)

TARDY, M., "ECLAIRS EN BOULE", METEOROLOGIE, 39,1891b,PG.285

TARDY, M., "ECLAIRS EN BOULE", METEOROLOGIE, 44,1896,PG.66

TASTES, M.DE, "L'ORAGE DU 1ER FEVRIER 1884, A TOURS", METEOROLOGIE, 32,1884, PG.105

TASTES, M.DE, "DAS GEWITTER", AMER.METEOROL.J., 2,1885a,PG.142

TASTES, M.DE, "DAS GEWITTER VOM 1 FEBRUAR 1884 IN TOURS", METEOROL.ZEIT., 2, 1885b,PG.114

TAYLOR, J.E., "PHOTOGRAPHY AND BALL LIGHTNING", WEATHER, 9,1954,PG.321

TAYLOR, W.D., "BALL LIGHTNING IN SOUTH WALES", METEOROL.RECORD, 4,1884,PG.4

TEICH, M., "EINE KUGELBLITZBEOBACHTUNG", ZEIT.METEOROL., 9,1955,PG.379

TELETOV, G.S., "BALL LIGHTNING" FROM PRIRODA, NO.9,1966,PG.84, IN FOREIGN SCIENCE BULL., 2,NO.12,1966a,PG.53

TELETOV, G.S., "BALL LIGHTNING" FROM PRIRODA, NO.9,1966,PG.84, IN JPRS-39032, U.S.DEPT.COMMERCE, WASHINGTON D.C., DEC.1966b

TELETOV, G.S., "SHAROVAYA MOLNIIA", PRIRODA, NO.9,1966c,PG.84

TERADA, T., "ON LUMINOUS PHENOMENA ACCOMPANYING EARTHQUAKES", TOKYO UNIV. EARTH- QUAKE RES.BULL., 9,1931,PG.225

TESLA, N., "UNAVAILABLE-TITLE UNKNOWN", ELECTRICAL ENGINEER (NY), 7,1891, PG.549 (NBL)

TESLA, N., "THE TRANSMISSION OF ELECTRICAL ENERGY WITHOUT WIRES", ELECTRICAL WORLD AND ENGINEER, 35,1904,PG.429

TESLA, N., IN "NIKOLA TESLA, LECTURES-PATENTS-ARTICLES", NOLIT PUBLISHING HOUSE, KULTURA PRESS, BEOGRAD, YUGOSLAVIA, 1956,PG.A-152

TESLA, N., "NIKOLA TESLA, COLORADO SPRINGS NOTES, 1899-1900", NIKOLA TESLA MUSEUM, NOLIT, BEOGRAD, YUGOSLAVIA, 1978

TESSAN, M.DE, "SUR LA FOUDRE EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 49,1859a, PG.189

TESSAN, M.DE, "SUR LA FOUDRE EN BOULE", (SUMMARY), FORTSCHR.PHYS., 15,1859b,PG.62

THATE, J.B., "BOLBLIKSEM TE WARNVELD OP 28 NOVEMBER 1951", HEMEL EN DAMPKRING, 50, 1952,PG.134 (*)

THERON, H., "LES CAPRICES DE LA FOUDRE, FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 11, 1897,PG.299

THOMPSON, D., "EXPLOSION OF A FIREBALL AT KAMARON ISLAND, RED SEA", ROY.METEOROL. SOC.Q.J., 71,1945,PG.39

THOMPSON, E., "ATMOSPHERIC ELECTRICITY", SCIENCE, 30,1909,PG.857

THOMPSON, E., "ATMOSPHERIC ELECTRICITY", (SUMMARY), FORTSCHR.PHYS., 66(3),1910, PG.334

THOMPSON, J.J., "ON THE DISCHARGE OF ELECTRICITY THROUGH EXHAUSTED TUBES WITHOUT ELECTRODES", PHIL.MAG., 32,1891,PG.320 AND PG.444 (NBL)

THOMPSON, W., "DISCUSSION ON LIGHTNING CONDUCTORS", BRITISH ASSO.ADV.SCI., 58,1888 PG.604

THORNTON, W.M., "ON THUNDERBOLTS", (SUMMARY), FORTSCHR.PHYS., 67(3),1911a,PG.342

THORNTON, W.M., "SUR LA FOUDRE GLOBULAIRE", J.PHYS.RAD., SER.5,1,1911b,PG.488

THORNTON, W.M., "ON THUNDERBOLTS", NATURWISS.RUND., 26,1911c,PG.409 (*)

THORNTON, W.M., "ON THUNDERBOLTS", PHIL.MAG., 6(21),1911d,PG.630

THORNTON, W.M., "UBER KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 68(3),1912a,PG.317

THORNTON, W.M., "UBER KUGELBLITZ", METEOROL.ZEIT., 29,1912b,PG.39

THORNTON, W.M., "UNAVAILABLE-TITLE UNKNOWN", LE COSMOS, 18,1913,PG.142

THOST, E., "EIN KUGELBLITZ", METEOROL.ZEIT., 48,1931,PG.269

TIKHOMNROV, E.I., "SHAROVAYA MOLNIYA I EE NOVAYA TEORIYA", KLIMAT I POGODA, NO.7, 1932,PG.109 (*)

TISSANDER, G., "ECLAIR EN CHAPELET OBSERVE AU-DESSUS DE PARIS", L'OCEAN AERIEN, G.MASON, PARIS, 1884,PG.151 (*)

TISSANDIER, G., "UN FOUDRE EN MER", LA NATURE, MARS,1887a,PG.254 (*)

TISSANDIER, G., "UN FOUDRE EN MER", METEOROLOGIE, 35,1887b,PG.221

TISSANDIER, G., "SUR LE CYCLONE DE LA MARTINIQUE DU 18 AOUT 1891", C.R.HEBD. SEANCES ACAD.SCI., 113,1891,PG.421

TOEPLER, M., "GESCHICHTETE ENTLADUNG IN FREIER LUFT", ANN.PHYSIK, 63,1897,PG.109

TOEPLER, M., "UNAVAILABLE-TITLE UNKNOWN", ABH.NATURWISS.GES.ISIS,DRESDEN, 1,1898a, PG.10

TOEPLER, M., "UEBER DIE EIGENSCHAFTEN DES GESCHICHTETEN BUSCHELLICHTBOGENS IN FREIER LUFT", ANN.PHYSIK, 66,1898b,PG.660 (NBL)

TOEPLER, M., "UEBER GLEITENDE ENTLADUNG LANGS EINER GLASOBERFLACHEN", ANN.PHYSIK, 66,1898c,PG.1061 (NBL)

TOEPLER, M., "VERHALTEN DES BUSCHELLICHTBOGENS IN MAGNETFELDE", ANN.PHYSIK, 69, 1899,PG.680 (NBL)

TOEPLER, M., "UEBER DIE ABHANGIGKEIT DES CHARAKTERS ELEKTRISCHER DAUERENTLADUNG IN ATMOSPHARISCHER LUFT VON DER DEM ENTLADUNGSRAUME KONTINUIELICH ZUGEFUHRTEN ELEKTRIZITATSMENGE, NEBST EINEM ANHANGE ZUR KENNTNIS DER KUGELBLITZE", ANN. PHYSIK, IV, 307,1900a,PG.560

TOEPLER, M., "L'ECLAIR EN BOULE", LE COSMOS, SEPT.,1900b,PG.287 (*)

TOEPLER, M., "ZUR KENNTNISS DER KUGELBLITZ", METEOROL.ZEIT., 17,1900c,PG.543

TOEPLER, M., "LE FOUDRE EN BOULE", CIEL ET TERRE, 21,1900/01,PG.401

TOEPLER, M., "EIN FLUSS VON DIAPHRAGMEN AUF ELEKTRISCHE DAUERENTLADUNG DURCH LUFT VON ATMOSPHARENDRUCK", ANN.PHYSIK, IV,6,1901a,PG.339

TOEPLER, M., "KUGELBLITZ", JAHRBUCH DER ASTRONOMIE UND GEOPHYSIK, 12,1901b,PG.409

TOEPLER, M., "UNAVAILABLE-TITLE UNKNOWN", L'ECLAIRAGE ELECTRIQUE, 26,1901c,PG.58

TOEPLER, M., "L'ECLAIR EN BOULE", METEOROLOGIE, 49,1901d,PG.53

TOEPLER, M., "FRAGEN ZUR ERFORSCHUNG DER KUGELBLITZ", METEOROL.ZEIT., 18,1901e, PG.533

TOEPLER, M., "GRENZPOTENTIALDIFFERENZEN DEN ELEKTRISCHEN ENTLADUNG IN LUFT VON ATMOSPHARENDRUCK", ANN.PHYSIK, 7,1902,PG.477 (NBL)

TOEPLER, M., "UBER FUNKENLAGEN UND ANFANGSSPANNUNGEN IN LUFT VON ATMOSPHARENDRUCK", ANN.PHYSIK., 10,1903,PG.730

TOEPLER, M., "UNAVAILABLE-TITLE UNKNOWN", ABH.NATURWISS.GES.ISIS,DRESDEN, 8,1916, PG.13

TOEPLER, M., "ZUR KENNTNIS DER GESETZE DER BILDUNG VON LEUCHTMASSEN

(PERLEN) BEI PERLSCHNURBLITZEN", METEOROL.ZEIT., 34,1917a,PG.225

TOEPLER, M., "UNAVAILABLE-TITLE UNKNOWN", VERBANDS MITT.D.DRESDNER ELEKTROTECHN. VEREINS U.D.DRESDNER BEZIRKSVEREINS DTSCH.ING., 22 FEB.1917b (*)

TOEPLER, M., "UNAVAILABLE-TITLE UNKNOWN", MITT.HERMSDORF-SCHOMBERG ISOLATOREM, 25,1926a,PG.18

TOEPLER, M., "UNAVAILABLE-TITLE UNKNOWN", MITT.HERMSDORF-SCHOMBERG ISOLATOREM, 25,1926b,PG.743

TOEPLER, M., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.TECH.PHYS., 10,1929,PG.113

TOEPLER, M., "BISHER UNBEKANNTE FORM DES ELMSFEUERS", NATURWISS., 1,1944,PG.365(*)

TOEPLER, M., "BLITZ", NATURWISS.RUND., 7,1954,PG.326

TOEPLER, M., "KUGELBLITZ, ST. ELMSFEUER", PHYS.BLATTER, 15,1959,PG.190

TOEPLER, M., "KUGELBLITZ UND ELMSFEUER?", PHYS.BLATTER, 16,1960,PG.348

TOMLINSON, C., "ON SOME EFFECTS OF LIGHTNING", PHIL.MAG., 26,1888a,PG.114

TOMLINSON, C., "REMARKS ON THE WEATHERING OF ROCKS AND CERTAIN ELECTRICAL PHENOMENA, SUGGESTED BY SOME STATEMENTS IN A POPULAR NOVEL", PHIL.MAG., 26, 1888b,PG.475

TOMLINSON, C., "ON THE WEATHERING OF ROCKS AND CERTAIN ELECTRICAL PHENOMENA", PHIL.MAG., 26,1888c,PG.484

TOMLINSON, C., "ON SOME EFFECTS OF LIGHTNING", NATURE, 40,1889,PG.366

TOMLINSON, C., "THE THUNDERSTORM", SPEK, 1895,PG.151 (*)

TOMPKINS, D.R., AND P.F.RODNEY, "PHOTOGRAPHIC OBSERVATIONS OF BALL LIGHTNING", TERRENE CORP., UNPUBLISHED REPORT, REFUGIO,TEXAS,USA,78377, OCT.1977

TOMPKINS, D.R., P.F.RODNEY AND R.GOODING, "PHOTOGRAPHIC OBSERVATIONS OF BALL LIGHTNING", BULL.AMER.PHYS.SOC., 20,1975,PG.659

TOMPKINS, D.R., P.F.RODNEY AND R.GOODING, "PHOTOGRAPHIC OBSERVATIONS OF BALL AND BEAD LIGHTNING", UNPUBLISHED REPORT, UNIVERSITY OF WYOMING, DEPT. OF PHYSICS AND ASTRONOMY, LARAMIE, WYOMING, 1976

TONKS, L., "ELECTROMAGNETIC STANDING WAVES AND BALL LIGHTNING", NATURE, 187,1960, PG.1013

TOTCH, L., "ECLAIR EN BOULE OBSERVE A PARIS", CIEL ET TERRE, 24,1903,PG.544

TOUCHET, E., "LES ORAGES D'AOUT ET SEPTEMBRE 1899", BULL.SOC.ASTRON.FR., 13,1899, PG.417

TOUCHET, E., "ECLAIR EN CHAPELET", BULL.SOC.ASTRON.FR., 45,1931,PG.84

TOUCHET, E., "OBSERVATION D'UN ECLAIR GLOBULAIRE (?)", BULL.SOC.ASTRON.FR., 46, 1932,PG.490

TOWNSEND, G.F., "UNAVAILABLE-TITLE UNKNOWN", ELECTR.REV., 26,1895a,PG.297

TOWNSEND, G.F., "A LIGHTNING PHOTOGRAPH", SCIENTIFIC AMERICAN, 72,1895b,PG.379

TOWNSEND, J.S., "THE CONDUCTIVITY PRODUCED IN GASES BY THE MOTION OF NEGATIVELY CHARGED IONS", NATURE, 63,1900,PG.340 (NBL)

TOWNSEND, J.S., "THE CONDUCTIVITY PRODUCED IN GASES BY THE MOTION OF NEGATIVELY CHARGED IONS", PHIL.MAG., 1,1901,PG.198 (NBL)

TRAMBORG, C., "KUGELBLITZ AUF SEE", ANN.HYDRO.MARIT.METEOROL., 32,1904,PG.390

TRAPP, E., "KUGEL BLITZERSCHEINUNG IN WEIN", WETTER UND LEGEN, 1,1949,PG.274

TRECUL, A., "UN EFFET DE FOUDRE PENDANT L'ORAGE DU 18 AOUT", C.R.HEBD.SEANCES ACAD.SCI., 83,1875,PG.478

TRECUL, A., "CAS REMARQUABLE DE TONNERRE EN BOULE; ECLAIRS DIFFUS VOISINS DE LA SURFACE DU SOL", C.R.HEBD.SEANCES ACAD.SCI., 92,1881a,PG.775

TRECUL, A., "CAS REMARQUABLE DE TONNERRE EN BOULE; ECLAIRS DIFFUS VOISINS DE LA SURFACE DU SOL", (SUMMARY), FORTSCHR.PHYS., 37(3),1881b,PG.534

TRECUL, A., "CAS REMARQUABLE DE TONNERRE EN BOULE; ECLAIRS DIFFUS VOISINS DE LA SURFACE DU SOL", MONDES, 54,1881c,PG.534 (*)

TRIER, O., "KUGELBLITZ-AUFNAHMEN", PHYS.BLATTER, 16,1960,PG.349

TRIPE, J.W., "REMARKS ABOUT BALL LIGHTNING", IN "REMARKS ON SOME PRACTICAL POINTS CONNECTED WITH THE CONSTRUCTION OF LIGHTNING CONDUCTORS", BY R.J. MANN, ROY. METEOROL.SOC.Q.J., 2,1875,PG.431

TRIPE, J.W., "BALL LIGHTNING SEEN DURING A THUNDERSTORM, ON JULY 11TH, 1874", ELECTRICIAN, 19,1887a,PG.179

TRIPE, J.W., "BALL LIGHTNING SEEN DURING A THUNDERSTORM ON JULY 11TH, 1874", METEOROL.MAG., 22,1887b,PG.88

TRIPE, J.W., "BALL LIGHTNING SEEN DURING A THUNDERSTORM ON JULY 11TH, 1874", AMER. J.METEOROL., 4,1888,PG.149

TROWBRIDGE, J., "EXPERIMENTAL BALL LIGHTNING", ASTROPHYS.J., MAY,1907a (*)

TROWBRIDGE, J., "BALL LIGHTNING", SCIENTIFIC AMERICAN, 96,1907b,PG.489

TROWBRIDGE, J., "LIGHTNING AND POWERFUL ELECTRIC DISCHARGES", MON.WEATHER REV., 36,1908,PG.92

TROWBRIDGE, J., "EXPERIMENTAL BALL LIGHTNING", (SUMMARY), FORTSCHR.PHYS., 66(3), 1910a,PG.358

TROWBRIDGE, J., "EXPERIMENTAL BALL LIGHTNING", KNOWLEDGE SCI.NEWS, 7,1910b,PG.282

TRUBNIKOV, B.A., "THE NATURE OF BALL LIGHTNING",

GEOPHYS.-DOKL.AKAD.NAUK.SSSR, 203 1972,PG.13, TRANSL. OF DOKL.AKAD.NAUK.SSSR(GEOFIZ.SER.), 203,1972,PG.1296

TSCHIRWINSKIJ, P.N., "ZUR THEORIE DER KUGELBLITZ", METEOROL.I.HYDROL.-MOSCOW, NO.3,1936,PG.78 (*)

TSCHIRWINSKIJ, P.N., "ZUR THEORIE DER KUGELBLITZ", ANN.HYDRO.MARIT.METEOROL., 67, 1939,PG.109 (*)

TUCK, J.L., "BALL LIGHTNING - A STATUS SUMMARY TO 1971", UNPUBLISHED REPORT, LA-4847-MS, LOS ALAMOS SCIENTIFIC LABORATORY, LOS ALAMOS, NEW MEXICO, USA, UC- 34, DEC. 1971

TURMAN, B.N., "DETECTION OF LIGHTNING THUNDERBOLTS", J.GEOPHYS.RES., 82,1977, PG.2566 (NBL)

TURMAN, B.N., B.C.EDGAR AND L.N.FRIESEN, "GLOBAL LIGHTNING DISTRIBUTION AT DAWN AND DUSK FOR AUGUST-SEPTEMBER 1977", PRESENTED AT THE AGU SPRING MEETING, APRIL 17-21, 1978, MIAMI BEACH,FLA, ABSTRACT IN EOS-TRANS.AGU, 59(4),1978,PG.285 (NBL)

TURNER, P., "ST.ELMO'S FIRE" FROM "SELECTIONS FROM THE HISTORY OF THE WORLD, THE NATURAL HISTORY OF G.PLINUS SECUNDUS", SOUTHERN ILLINOIS UNIVERSITY PRESS, CARBONDALL, ILL., 1962,PG.34 (NBL)

TURPAIN, M.A., "CURIEUX EFFECTS D'UN COUP DE FOUDRE SUR UNE ANTENNE RECEPTRICE D'ONES ELECTRIQUE", J.PHYS.RAD., SER.5,1,1911,PG.372

TVERSKOY, P.N., "ATMOSFERNOYE ELEKTRICHESTVO", MOSCOW-LENINGRAD, 1949 (*)

TWENEY, C.F. AND C.F.SHIRSHOV-EDS, "HUTCHINSON'S TECHNICAL AND SCIENTIFIC ENCYLOPEDIA", MACMILLAN CO., NEW YORK, 1,1936,PG.193

UMAN, M.A., "BEAD LIGHTNING AND THE PINCH EFFECT", J.ATMOS.TERR.PHYS. 24,1962, PG.43

UMAN, M.A., "THE DIAMETER OF LIGHTNING", J.GEOPHYS.RES., 69,1964,PG.583 (NBL)

UMAN, M.A., "DECAYING LIGHTNING CHANNELS, BEAD LIGHTNING, AND BALL LIGHTNING, WESTINGHOUSE RESEARCH LABS, SCIENTIFIC PAPER L7-9E4-HIVOL-P7, PITTSBURGH, PA,USA NOV., 1967

UMAN, M.A., "SOME COMMENTS ON BALL LIGHTNING", J.ATMOS.TERR.PHYS., 30,1968a, PG.1245

UMAN, M.A., "DECAYING LIGHTNING CHANNELS, BEAD LIGHTNING, AND BALL LIGHTNING", IN "PLANETARY ELECTRODYNAMICS", S.C.CORONITI AND J.HUGHES-ED., GORDON AND BREACH NEW YORK, VOLUME 2,1968b,PG.199

UMAN, M.A., "LIGHTNING", MCGRAW-HILL, NEW YORK, 1969,PG.240

UMAN, M.A. AND C.W.HELSTROM, "A THEORY OF BALL LIGHTNING", J.GEOPHYS.RES., 71,1966 PG.1975

UMAN, M.A. AND R.E.ORVILLE, "THE OPACITY OF LIGHTNING", J.GEOPHYS.RES., 70,1965, PG.5491 (NBL)

UMAN, M.A. AND R.E.VOSHALL, "TIME INTERVAL BETWEEN LIGHTNING STROKES AND THE INITIATION OF DART LEADERS," J.GEOPHYS.RES., 73,1968,PG.497 (NBL)

URBANITZKY, A.VON, "BLITZ UND BLITZ-SCHUTZVORRICHTUNGEN", ELEKTROTECHNISCHE BIBLIOTHEK, 1886 (*)

URBANITZSKY, A.VON, "DIE ELEKTRIZITAT DES HIMMELS UND DER ERDE", WIEN-BERLIN, 1888,PG.78 (*)

VANDEPERRE, G.F., "UNAVAILABLE-TITLE UNKNOWN", ELEKTROTECH., 11,1924,PG.271

VANNESSON, G., "UNAVAILABLE-TITLE UNKNOWN", L'ASTRONOMIE, 5,1886,PG.431 (*)

VARLEY, F., "SOME EXPERIMENTS ON THE DISCHARGE OF ELECTRICITY THROUGH RARIFIED MEDIA AND THE ATMOSPHERE", ROY.SOC.LOND.PROC., 19,1871,PG.236

VARLEY, F., "UNAVAILABLE-TITLE UNKNOWN", J.SOC.TEL.ENGR., 1,1872,PG.368

VAUGHAN, O.H. AND B.VONNEGUT, "LUMINOUS ELECTRICAL PHENOMENA IN HUNTSVILLE, ALABAMA, TORNADOES", UNPUBLISHED, NASA/MSFC, 1976 (NBL)

VERDET, M., "UNAVAILABLE-TITLE UNKNOWN", LA NATURE, 18,1890,PG.203 AND 303 (*)

VIEMEISTER, P.E., "THE LIGHTNING BOOK", DOUBLEDAY AND CO., NEW YORK, 1961,PG.130

VILLEMONTEE, G.G.DE, "SUR UN CAS DE FOUDRE GLOBULAIRE", C.R.HEBD.SEANCES ACAD. SCI., 155,1912a,PG.1567

VILLEMONTEE, G.G.DE, "SUR UN CAS DE FOUDRE GLOBULAIRE", METEOROLOGIE, 60,1912b, PG.307

VIOLLE, J., "SUR UN ECLAIR EN BOULE", C.R.HEBD.SEANCES ACAD.SCI., 132,1901a, PG.1537

VIOLLE, J., "LA FOUDRE EN BOULE", CIEL ET TERRE, 22,1901b,PG.479

VIOLLE, J., "KUGELBLITZ", NATURWISS.RUND., 16,1901c,PG.504

VIOLLE, J., "KUGELBLITZBEOBACHTUNG", METEOROL.ZEIT., 19,1902,PG.335

VIRIER, M., "LA NOTE", C.R.HEBD.SEANCES ACAD.SCI., 139,1904,PG.904

VISSER, S.W., "TWEE BLIKSENBALLEN BIJ LAREN", HAMEL EN DAMPKRING, 55,1957a, PG.45 (*)

VISSER, S.W., "UNAVAILABLE-TITLE UNKNOWN", HIMMEL UND ERDE, 55,1957b,PG.54

VISSER, S.W., "SOME REMARKS ON LIGHTNING FLASHES AND BALL LIGHTNING", METEOROL. MAG., 86,1957c,PG.344

VLASOV, A.A., "UNAVAILABLE-TITLE UNKNOWN", SCI.SINICA, 8,1959,PG.266

VLASOV, A.A. AND M.A.YAKORLEV, "INTERACTION BETWEEN IONS THROUGH AN INTERMEDIATE SYSTEM (NEUTRAL GAS) AND THE PROBLEM OF THE EXISTANCE OF A SELF MAINTAINING SWARM OF PARTICLES (BALL LIGHTNING)", VESTN.MOSK.UNIV.FIZ.ASTRON.(USSR), 16, NO.3,1975,PG.332 (*)

VOGEL, M., "BEOBACHTUNG EINES KUGELBLITZES", ZEIT.ANGEW.METEOROL., 58,1941, PG.124 (*)

VOITSEKHOVSKII, B.V. AND B.B.VOITSEKHOVSKII, "PRIRODA SHAROVOY MOLNII", AKAD.NAUK. SSSR DOKL.MAT.FIZ., 218,1974,PG.77

VOITSEKHOVSKII, B.V. AND B.B.VOITSEKHOVSKII, "THE NATURE OF BALL LIGHTNING", SOV.PHYS.-DOKL., 19,1975,PG.580, ENGLISH TRANSLATION OF AKAD.NAUK.SSSR DOKL. MAT.FIZ., 218,1974,PG.77

VOITSEKHOVSKII, B.V. AND B.B.VOITSEKHOVSKII, "ELEKTROMEKHANICHESKIE EFFEKTY V SHAROVOI MOLNII", AKAD.NAUK.SSSR, SIBIRSKOE OTDELENIE, IZVESTIIA, SERIIA TEKNICHESKIKH NAUK., FEB., 1976 (*)

VOLLER, C.R., "UNAVAILABLE-TITLE UNKNOWN", ELEKTRO.ZEIT., 9,1888,PG.473

VOLMER, C.R., "EIN KUGELBLITZ IN PADERBORN", (SUMMARY), FORTSCHR.PHYS., 52(3), 1896a,PG.298

VOLMER, C.R., "UNAVAILABLE-TITLE UNKNOWN", ZEIT.ANGEW.METEOROL., 13,1896b,PG.185

VOLMER, C.R., "KUGELBLITZ", METEOROL.ZEIT., 14,1897,PG.34

VONNEGUT, B., "ELECTRICAL THEORY OF TORNADOES", J.GEOPHYS.RES., 65,1960, PG.203 (NBL)

VONNEGUT, B. AND J.R.WEYER, "LUMINOUS PHENOMENON IN NOCTURNAL TORNADOES", SCIENCE, 153,1965,PG.1213 (NBL)

VONNEGUT, B., C.B.MOORE AND C.K.HARRIS, "STABILIZATION OF A HIGH VOLTAGE DISCHARGE BY A VORTEX", J.METEOROL.(NOW J.ATMOS.PHYS.), 14,1960,PG.468 (NBL)

WAGNER, A., "KUGELBLITZ", METEOROL.ZEIT., 56,1939,PG.350

WAGNER, C.F. AND G.C.MC CANN, "UNAVAILABLE-TITLE UNKNOWN", ELECTR.ENGR., 60,1941, PG.374

WAGNER, G.A., "OPTICAL AND ACOUSTIC DETECTION OF BALL LIGHTNING", NATURE, 232, 1971,PG.187

WAINHOUSE, W. AND R.PITCAIRN, "ACCOUNT OF THE EFFECTS OF LIGHTNING AT STEEPLE ASHTON AND HOLT, IN THE COUNTY OF WILTS ON THE 20TH OF JUNE 1772, CONTAINED IN SEVERAL LETTERS", ROY.SOC.LOND.PHIL.TRANS., 63,1773,PG.234

WALTER, B., "ZUR ERKLARUNG DER WOLFSCHEN BLITZPHOTOGRAPHIE", ANN.HYDRO.MARIT. METEOROL., 30,1902,PG.579

WALTER, B., "UBER DIE WOLFFSCHE BLITZPHOTOGRAPHIE", ANN.HYDRO.MARIT.METEOROL., 31, 1903a,PG.65

WALTER, B., "UBER DIE ENTSTEHUNGSWEISE DER BLITZEN", ANN.PHYSIK, 10,1903b,PG.393

WALTER, B., "UNAVAILABLE-TITLE UNKNOWN", JAHR.HAMBURG-WISS.ANSL., 20,1903c

WALTER, B., "UNAVAILABLE-TITLE UNKNOWN", HANDWERK-BUCH DER NATURWISSENSCHAFTEN, 1909a (*)

WALTER, B., "UBER KUGELBLITZ", METEOROL.ZEIT., 26,1909b,PG.217

WALTER, B., "KUGELBLITZ", METEOROL.ZEIT., 28,1911,PG.582

WALTER, B., "DAS WESEN DER KUGELBLITZE", (SUMMARY), FORTSCHR.PHYS., 71(3),1915a, PG.250

WALTER, B., "DAS WESEN DER KUGELBLITZE", PROMETHEUS, 26,1915b,PG.408 (*)

WALTER, B., "ERDBALL UND WELTALL", H.BERMUHLER, BERLIN-LICHTERFELDE, 1928 (*)

WALTER, B., "UBER DIE SURINGJCHE BLITZAUFNAHME, SOWIE UBER EINE NEUE, VERMEINTLICHE KUGELBLITZ-AUFNAHMEN", PHYS.ZEIT., 30,1929,PG.26

WARTMANN, A., "LA FOUDRE GLOBULAIRE", LA NATURE, MARCH,1888a,PG.226 (*)

WARTMANN, A., "COUP DE FOUDRE EN BOULE", LE COSMOS, FEVRIER 1888b,PG.279 (*)

WARTMANN, A., "UEBER EINEM KUGELBLITZ", ARCH.SCI.PHYS.NATUR., 21(1),1889a, PG.75 (*)

WARTMANN, A., "UEBER EINEN KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 45(3),1889b, PG.506

WARTMANN, A., "UEBER EINEN KUGELBLITZ", LA NATURE, 8(823),1889c,PG.226 (*)

WARTMANN, A., "COUP DE FOUDRE EN BOULE", METEOROLOGIE, 37,1889d,PG.102

WARTMANN, A., "LA FOUDRE GLOBULAIRE", METEOROLOGIE, 37,1889e,PG.148

WARTMANN, A., "UBER EINEN KUGELBLITZ", METEOROL.ZEIT., 6,1889f,PG.119

WARTMANN, A., "KUGELBLITZ", ZEIT.ANGEW.METEOROL., 6,1889g,PG.90

WARTMANN, A., "FOUDRE EN BOULE", BULL.SOC.ASTRON.FR., 11,1897,PG.29

WASSE, J., "TWO LETTERS ON THE EFFECTS OF LIGHTNING", ROY.SOC.LOND.PHIL.TRANS., 33,1725,PG.366

WATKINS, D.C., J.D.COBINE AND B.VONNEGUT, "ELECTRIC DISCHARGES INSIDE TORNADOES", SCIENCE, 199(4325),1978,PG.171 (NBL)

WATSON, W., "A LETTER TO THE ROYAL SOCIETY CONCERNING THE ELECTRICAL EXPERIMENTS IN ENGLAND ON THUNDER CLOUDS", PHIL.TRANS.ROY.SOC.LOND., 47,1752a,PG.565 (NBL)

WATSON, W., "AN ACCOUNT OF MR. BENJAMIN FRANKLIN'S TREATISE, LATELY PUBLISHED, INTITULED, EXPERIMENTS AND OBSERVATIONS ON ELECTRICITY, MADE AT PHILADELPHIA IN AMERICA", ROY.SOC.LOND.PHIL.TRANS., 47,1752b,PG.202 (NBL)

WATSON, W., "AN ANSWER TO DR. LINING'S QUERY RELATING TO THE DEATH OF PROFESSOR RICHMAN", ROY.SOC.LOND.PHIL.TRANS., 48,1754,PG.765

WATSON, W.K.R., "A THEORY OF BALL LIGHTNING FORMATION", NATURE 185,1960,PG.449

WATT, A.D., "CHARACTERISTICS OF ATMOSPHERIC NOISE FROM 1 TO 100 KC", PROC.IRE, 45,1957,PG.787

WAYE, B.E., "GLOBE LIGHTNING", NATURE, 155,1945,PG.752

WEBB, S., "LETTERS TO THE EDITOR", NATURE, 61,1900,PG.343

WEBBER, H., "A CASE OF GLOBULAR LIGHTNING", J.ROY.ASTRO.SOC.CANADA, 1,1907,PG.44

WEBER, L., "UNAVAILABLE-TITLE UNKNOWN", SCHR.NAT.VER.SCH.HOLST., 2,1879,PG.28

WEBER, L., "UNAVAILABLE-TITLE UNKNOWN", SCHR.NAT.VER.SCH.HOLST., 3,1880,PG.107

WEBER, L., "UNAVAILABLE-TITLE UNKNOWN", SCHR.NAT.VER.SCH.HOLST., 4,1881a,PG.48

WEBER, L., "UNAVAILABLE-TITLE UNKNOWN", SCHR.NAT.VER.SCH.HOLST., 4,1881b,PG.82

WEBER, L., "UNAVAILABLE-TITLE UNKNOWN", SCHR.NAT.VER.SCH.HOLST., 4,1882,PG.105

WEBER, L., "UNAVAILABLE-TITLE UNKNOWN", SCHR.NAT.VER.SCH.HOLST., 5,1883a,PG.27

WEBER, L., "UNAVAILABLE-TITLE UNKNOWN", SCHR.NAT.VER.SCH.HOLST., 5,1883b,PG.41

WEBER, L., "UNAVAILABLE-TITLE UNKNOWN", SCHR.NAT.VER.SCH.HOLST., 5,1883c,PG.52

WEBER, L., "EIN MERKWURDIGER BLITZSCHLAG ZU RIBNITZ AM 30.JULI 1884", METEOROL. ZEIT., 1,1884,PG.405

WEBER, L., "UEBER DEN GEGENWARTIGEN STAND DER KUGELBLITZ-FRAGE", AMER.METEOROL.J., 2,1885a,PG.142

WEBER, L., "UEBER DEN GEGENWARTIGEN STAND DER KUGELBLITZFRAGE", ELECTR.ZEIT., 6, 1885b,PG.401 (*)

WEBER, L., "UEBER DEN GEGENWARTIGEN STAND DER KUGELBLITZFRAGE", (SUMMARY), FORTSCHR.PHYS., 41(3),1885c,PG.652

WEBER, L., "UEBER DEN GEGENWARTIGEN STAND DER KUGELBLITZFRAGE", GAEA, 10,1885d (*)

WEBER, L., "UEBER DEN GEGENWARTIGEN STAND DER KUGELBLITZ-FRAGE", METEOROL.ZEIT., 2,1885e,PG.118

WEBER, L., "BEOBACHTUNG UBER KUGELBLITZ", ZEIT.ANGEW.METEOROL., 13,1896,PG.36 (*)

WEBER, L., "KUGELBLITZE", METEOROL.ZEIT., 28,1911,PG.582

WEBER, L., "KUGELBLITZE", METEOROL.ZEIT., 32,1915,PG.22

WEEKES, W.H., "BALL LIGHTNING", ANN.ELECT.MAGNET.CHEM.GUARD.EXPR.SCI., 7,1841, PG.243

WEGENER, A., "LITERATURBERICHT; BRAND,W.: DER KUGELBLITZ", METEOROL.ZEIT., 40, 1923,PG.381

WELKER, P.A., "ELECTRIC STORM ON MOUNT ELBERT, COLORADO", SCIENCE, 2(36),1895, PG.304

WELKER, P.A., "EINE ELEKTRISCHE ERSCHEINUNG AUF MOUNT ELBERT", ZEIT.ANGEW. METEOROL., 13,1896,PG.153 (*)

WENDT, O., "FLACHENBLITZ ODOR KUGELBLITZ", (SUMMARY), FORTSCHR.PHYS., 62(3),1906a, PG.287

WENDT, O., "FLACHENBLITZ ODER KUGELBLITZ", ZEIT.ANGEW.METEOROL., 23,1906b, PG.41 (*)

WESTPHAL, W., "BEOBACHTUNG EINES KUGELBLITZES", NATURWISS., 19,1931,PG.19

WESTPHAL, W., "PHOTOGRAPHIERTE BLITZ", PHYS.BLATTER, 14,1958,PG.573

WHIPPLE, F.J.W., "BALL LIGHTNING SEEN AT ST. JOHN'S WOOD", METEOROL.ZEIT., 56, 1921,PG.195

WHITE, E.H., E.RAPAPORT, H.H.SELIGER AND T.A.HOPKINS, "THE CHEMI- AND BIOLUMINESCENCE OF FIREFLY LUCIFERIN: AN EFFICIENT PRODUCTION OF ELECTRICALLY EXCITED STATES", BIOORGANIC CHEM., 1(1/2),1971,PG.92 (NBL)

WILKINSON, J., "AN EXAMPLE OF BALL LIGHTNING", ROY.ASTRON.SOC.CANADA J., 25,1931, PG.322

WILSON, C.T.R., "A THEORY OF THUNDERCLOUD ELECTRICITY", ROY.SOC.LOND.PROC., 236, 1956,PG.297

WILSON, J.G., "ST.ELMO'S FIRE", MARINE OBSERVER, 24,1954,PG.10 (NBL)

WILSON, M., "TITLE UNKNOWN-UNAVAILABLE", J.ROY.GEOGR.SOC., 35,1865 (*)

WIMBUSH, B.S., "BALL LIGHTNING", ROY.ASTRON.SOC.CANADA J., 18,1924,PG.282

WINCHESTER, G., "A PARTICULAR LIGHTNING PHENOMENON", SCIENCE, 70,1929,PG.501

WIRTZ, C., "BEOBACHTUNG EINER KUGELBLITZARTIGEN ERSCHEINUNG IN KIEL", ANN.HYDRO. MARIT.METEOROL., 48,1920,PG.234

WISLICENUS, G., "UEBER SANCT-ELMSFEUER UND KUGELBLITZE AUF HOHER SEE", (SUMMARY), FORTSCHR.PHYS., 50(3),1894a,PG.422

WISLICENUS, G., "UEBER SANCT-ELMSFEUER UND KUGELBLITZE AUF HOHER SEE", PROMETHEUS, 6,1894b,PG.36 (*)

WITTMANN, A., "IN SUPPORT OF A PHYSICAL EXPLANATION OF BALL LIGHTNING", NATURE, 232,1971,PG.625

WITTMANN, A., "GIBT ES KUGELBLITZ?", UMSCHAU WISS.TECH., 76(16),1976,PG.516

WOJSKOWY, M., "UNTITLED TRANSLATION", FROM PRZEGLAD LOTNICZY, NO.12,1966,PG.12, IN FOREIGN SCIENCE BULL., 2,NO.4,APPENDIX II,1966,PG.52

WOLF, F., "DAS GEWITTER UND SEINE ENTLADUNGSFORMEN. I. TEIL: GEWITTERENTSTEHUNG UND LINIENBLITZ", NATURWISS., 31(7/8),1943a,PG.73

WOLF, F., "DAS GEWITTER UND SEINE ENTLADUNGSFORMEN. II. TEIL: KUGELBLITZE UND PERLSCHNURBLITZE", NATURWISS., 31,1943b,PG.215

WOLF, F., "INTERESSANTE AUFNAHME EINES KUGELBLITZES", NATURWISS., 43,1956a,PG.415

WOLF, F., "INTERESSANTE AUFNAHME EINES KUGELBLITZES", ORION, 4,1956b,PG.589

WOLF, F., "PHOTOGRAPHIERTE BLITZ", PHYS.BLATTER, 14,1958,PG.573

WOLF, K., "DAS WESEN DER KUGELBLITZ", METEOROL.ZEIT., 32.1915a,PG.416

WOLF, K., "DAS WESSEN DER KUGELBLITZ", PROMETHUS, 26,1915b,PG.229 (*)

WOLF, K., "DAS WESEN DER KUGELBLITZE (EINE ENTGEGNUNG)", PROMETHEUS, 26,1915c, PG.586 (*)

WOLF, K., "THE NATURE OF BALL LIGHTNING", SCI.AMERICAN SUPPL., 80,1915d,PG.54

WOLFF, C., "VERNUFTIGE GEDANKEN VON DEN WIRKUNGEN DER NATUR", HALLE, 1725, PG.471 (*)

WOOD, R.W., "BALL LIGHTNING", NATURE, 126,1930a,PG.723

WOOD, R.W., "PLASMOIDAL HIGH FREQUENCY OSCILLATING DISCHARGES IN NON-CONDUCTING VACUA", PHYS.REV., 35,1930b,PG.673

WOODING, E.R., "BALL LIGHTNING", NATURE, 199,1963,PG.272

WOODING, E.R., "LASER ANALOGUE TO BALL LIGHTNING", NATURE, 239,1972,PG.394

WOODING, E.R., "BALL LIGHTNING IN SMETHWICK", NATURE, 262,1976,PG.379

WOOR, R.W., "PLASMOIDAL HIGH FREQUENCY OSCILLATING DISCHARGES IN NON-CONDUCTING VACUA", PHYS.REV., 35,1930,PG.673 (NBL)

WORDINGHAM, C.H., "GLOBE LIGHTNING", ELECTRICIAN, 22,1888,PG.56

WORKMAN, E.J. AND R.E.HOLTZER, "AN ANOMOLOUS LIGHTING PHOTOGRAPH", PHYS.REV., 51, 1937,PG.149

WORLOCK, R.M., "A PROPOSAL FOR LABORATORY STUDIES OF BALL LIGHTNING AND CHARGED PARTICLE CONTAINMENT", UNPUBLISHED, ELECTRO-OPTICAL SYSTEMS,INC.,PASADENA,CA, OCTOBER,1960

WORMELL, W.T., "SYMONS MEMORIAL LECTURE", ROY.METEOROL.SOC.Q.J., 79,1953,PG.474

YAFFEE, M., "AIR TRANSPORT LIGHTNING STRIKES STUDIED", AVIATION WEEK AND SPACE TECHNOLOGY, DEC.11,1972,PG.34

YANKOV, V.V., "BEHAVIOR OF A CONDUCTING GASEOUS SPHERE IN A QUASI-STATIONARY ELECTROMAGNETIC FIELD", ZH.EKSP.TEOR.FIZ., 36,1959,PG.560, ENGLISH TRANSLATION IN "BALL LIGHTNING", D.J.RITCHIE-ED, CONSULTANTS BUREAU, NEW YORK, 1961a

YANKOV, V.V., "DYNAMICS OF A CONDUCTING GASEOUS SPHERE IN A QUASI-STATIONARY ELECTROMAGNETIC FIELD", ZH.EKSP.-TEOR.FIZ., 37,1959,PG.224, ENGLISH TRANSLATION IN "BALL LIGHTNING", D.J.RITCHIE-ED, CONSULTANTS BUREAU, NEW YORK, 1961b

YATES, T.F., "BALL LIGHTNING", MON.WEATHER REV., 26,1898,PG.565

YELISEYEV, A., "VOZNIKNOVENIYE NAUKI OB ELEKTRICHESTVE V ROSSII", MOSCOW, 1960 (*)

YOUNG, C.J., "LIGHTNING FREAKS AT PETERBOROUGH", THE PETERBOROUGH CITIZEN, LONDON, 25 SEPT. 1934

YOUNG, G.A., "A LIGHTNING STRIKE OF AN UNDERWATER EXPLOSION PLUME", NOLTR 61-43, NAVAL SURFACE WEAPONS CENTER, WHITE OAK LAB, SILVER SPRING, MD., 1962

YUR'YEV, A., "THE SECRET OF BALL LIGHTNING", KOMSOMOL'SHAYA PRAVDA, 3,1960,PG.5(*)

ZAITSEV, A.V., "NEW THEORY OF BALL LIGHTNING", SOV.PHYS.-TECH.PHYS., 17,1972, PG.173, TRANSLATED FROM ZH.TEKH.FIZ., 42,NO.1,1972,PG.213

ZALESSKII, Y.M., "NAELEKTRIZOVANNYI SNEG I SHAROVAYA MOLNIIA ZIMOI", PRIRODA, NO.10,1958,PG.114

ZAPLETAL, G., "KUGELBLITZ SCHLINS-JUPIDENT", WETTER UND LEBEN, 22,1970,PG.193

ZENGER, C.V., "LES FIGURES ELECTRIQUES DESSINEES PAR L'ECLAIR", C.R.HEBD.SEANCES ACAD.SCI., 109,1889,PG.294

ZIMMERMAN, P.D., "ENERGY CONTENT OF COVINGTON'S LIGHTNING BALL", NATURE, 228,1970, PG.853

ZOEGE-VON-MANTEUFFEL, P., "EINE BLITZAUFNAHME", UMSCHAU WISS.TECH., 42,1938,PG.587

ZOEGE-VON-MANTEUFFEL, P., "EINE BLITZAUFNAHME", ORION, 4,1955,PG.589

ZSCHOKKE, W., "EIN KUGELBLITZPHOTOGRAPHIE?", PROMETHEUS, 14,1903a,PG.234 (*)

ZSCHOKKE, W., "EIN KUGELBLITZPHOTOGRAPHIE?", PROMETHEUS, 14,1903b,PG.691 (*)

ZUCCHER, M. AND M.MARGOLLE, "TROMBES ET CYCLONES", HACHETTI ET CIE, PARIS, 1876, PG.101

ZURCHER, M., "COUP DE FOUDRE", LA NATURE, SEPT.,1889a,PG.263 (*)

ZURCHER, M., "COUP DE FOUDRE", METEOROLOGIE, 37,1889b,PG.261

Index

Abbot, C. G., 86, 142
Accidental formation, 57
Acoustical oscillations, 31
Acoustical power, 61
Aerosols, electrified, charged, 172
Afterimages, 136
Air
  breakdown of, 2, 196
  glowing, spectra of, 189
  plasma, 64, 68, 184, 186, 195
Aircraft
  damage of, 38
  sightings from, 38, 42, 43, 186
Aitken, M., 74
Altitude of ball lightning observations, 42
Altschuler, M., 49, 73
Anderson, F. J., 55
Arabadji, V. I., 8
Arago, F., 133, 157
Arc formation, 123
Argyle, M., 137
Arrhenius, S. A., 12
Artificial phenomena, 60, 122, 180
Ashby, D. E. T. F., 63
Atkinson, G. W., 83
Atmospheric electricity, 1
Atom density, 61
Attraction of ball lightning to enclosures, 42, 43
Autokinetic effects, 138
Automated camera photographs, 23, 97, 144

Babat, G. I., 182, 200
Baljasni, W., 163
Ball lightning
  altitude of observations of, 42
Ball lightning (*cont.*)
  attraction to enclosures, 42
  characteristics of, 34, 45
  color of, 35
  damage and heat, 38
  death by, 38, 149
  decay of, 39
  deduced characteristics, 45
  diameter of, 35, 47, 66, 67, 76, 138, 173
  ejected material from, 101, 103
  electric field of, 41, 116, 196
  energy density of, 46
  energy relations, 66
  existence of, 3
  experiments, 147
  general characteristics of, 33
  historical observations of, 33
  hovering within room, 37, 42, 43
  in barrel, 48
  intensity modulation of, 17, 80, 82, 83
  lifetime of, 39
  lightning dependence, 39
  magnetic field of, 75, 116
  mass density of, 45
  motion of, 36
  movement against the wind, 37, 197
  observed properties of, 35
  odor of, 37
  optical diameter of, 48, 51, 77
  photographs of, 79, 130, 139, 140
  pressure of, 60
  radiation from, 73
  references to, 42, 43, 81, 204
  shape of, 35
  size of, 35, 76, 138, 173, 200
  skepticism, 133
  sound of, 37

Ball lightning (*cont.*)
storm dependence of, 39, 91
streamers from, 100, 124
structure of, 36
temperature of, 70, 73, 173, 193
wind effect on, 36, 41
Ball of fire, 170
Baltin, H., 130
Balyberdin, V. V., 63, 186
Baratoux, M., 47
Barry, J. D., 49, 59, 77, 145, 169
Bass, R., 180
Bauer, C., 89, 139
Bauman, G., 91, 143
Bead lighting
appearance of, 3, 11, 141, 153
description of, 11
drawings of, 17
experiments, 25
origins of, 28, 147, 153
photographs of, 12, 139, 141
references to, 13, 204
Behn, U., 12, 16, 85
Berger, K., 103, 133, 141, 195
Bioluminescence, 73
Blackbody radiation, 70
Blair, A., 75
Bodily harm, 38, 51
Bohr, N., 134
Boys, C. V., 48
Brand, W., 58, 105, 134, 146
Brook, M., 176
Bubbles, 165
Buchsbaum, S. J., 20

CO_2 molecule
emission, 130, 146, 189, 197
excitation, 193, 199
Caballero, E., 133
Cade, C. M., 20
Camera motion, 12, 16, 85, 89, 111, 120, 141
Carpenter, D. G., 48
Cartwright, J., 110
Cawood, W., 172
Cerrillo, M., 182, 200, 201
Charged aerosols, 172
Charman, W., 107
Color
of ball lightning, 35, 70
Color (*cont.*)
changes, 35, 36, 83
temperature, 70, 73, 85
Combustion, 59, 173, 175
Conclusions, 201
Cool oxidation, 174
Copper
ball, 56, 177
atoms, 57, 177
Corona discharge, 124, 197
Covington, A. E., 49

Damage by ball lightning, 38, 39
Dart
leader, 2, 24, 118, 124
stoke, 2, 24, 122, 124
Dashed traces, 24, 80
Davidov, B. V., 114, 143
Davis, D. W., 20, 84
Death by ball lightning, 38, 149
Decay of ball lightning, 39
Deduced characteristics of ball lightning, 45
Diameter of ball lightning, 35, 48, 66, 76, 138, 173
Dixon, F. E., 114
Dmitriev, M. T., 52, 71, 81, 115, 144
Dotted path, 11, 24, 80
Dunn, M., 131
Duplicate traces, 14, 85
Dust devils, 40

Earthquake observations, 41, 112
Eclairs en boule, 11, 157
Ejected material from ball lightning, 101, 103
Electric field of ball lightning, 41, 116, 196
Electrified aerosols, 172
Electrodeless discharges, 127, 180
Electroluminescence, 193
Electron exchange energy, 71
Emission spectra, 189
Emotion caused by observations, 34
End-on view of lightning channel, 18
Energy density
of ball lightning, 46, 66
of fully ionized air, 64
Energy distribution of ball lightning, 46
Energy interpretations, 64

Energy source, 43, 77
Energy storage by air molecules, vi, 189, 199
Eriksson, A. J., 99, 100, 144, 199
Erosion plasma, 179
Erroneous photographs, 139
Etta, A. I. I., 197
Exchange energy, 71
Experimental formation of ball lightning, 122, 140, 145, 149, 157, 176, 180
Experimental methods, 148, 157, 176, 180, 194
Explosive decay, 39, 68, 77, 174
External energy source, 201

Faraday, M., 133, 157
Fehr, U., 169
Fiery ball lightning, 101, 104
Fieux, R., 22, 152, 196
Finkelstein, D., 58, 66, 68, 73, 77, 129, 186, 194, 197, 199
Fireball
  combustion, 59, 169
  submarine, 56, 146, 177
Fire damp, 80
Firefly emissions, 73
Fireworks, 101, 143
Flammarion, C., 4, 33
Flash of lightning, 2
Flemming, S., 74
Formaldehyde oxidation, 174
Formation of ball lightning at a lightning channel bend, 91, 93
Foudre globulaire, 33
Franklin, B., 1
Freier, G. D., 56
Frequency of ball lightning occurrence, 6, 25, 97
Fully ionized plasma, 46, 63

Galli, I., 163
Gamma rays, 74
Gas law, 50
Gas samples, 53
Gaseous electric discharge, 157
Geist, F., 107
Generator shorting, 56, 58, 106, 146, 176, 177
Glow discharge, 122
Glowing air mass, 61, 186
Gold ring, 51
Golde, R. H., 195
Golka, R., 25, 180
Goodlet, B. L., 47
Green fireball, 56

Haidinger, H. von, 104, 143
Hamilton, G., 127, 184
Harrison, E. R., 184
Hatch, H. J., 127, 145
Heat, 38
Hesehus, N., 163, 165
Hildebrandsson, H., 77, 163, 169
Hill, F. L., 31, 49, 74
Historical observations of ball lightning, 33
Hubert, P., 22, 146, 153, 175, 196
Humphreys, W. J., 133
Hydrocarbon gases, 59, 77, 145, 163, 166, 172, 175

Image halo, 122
Indrikson, J., 163
Induced lightning discharges, 20, 141, 149, 152
Inferences, 76
Infrared radiation, 59, 77
Intensity modulation of ball lightning, 17, 80, 82, 83

Jack, H., 89
Jans, C. de, 33, 163, 201
Jefferson, G. T., 139
Jennings, R. C., 82, 142
Jensen, J. C., 92, 101, 143
Journals, 280

Kaptiza, P. L., 77, 131, 200
Kilinski, K. von, 16
Kip, A., 124, 128
Kugelblitz, 33
Kuhn, E., 104, 116, 143

Laboratory investigations, 122, 127, 140, 145, 149, 157, 176, 180
Laser experiments, 174
Leader stroke, 2, 195
Leduc, S., 163
Leonov, R., 144, 149
Lepel, F. von, 162

Lewis, G., 173
Lewis, H. W., 20
Leyden jar, 157, 159
Lifetime of ball lightning, 39
Lightning
  charge transfer, 2, 196, 199
  description of, 1, 118, 195
  duration of, 2
  experiments, 149
  frequency of occurrence, 97
  induced, 22, 152
  velocity of, 2. 23, 119
Lightning channel
  decay of, 91, 99
  diameter of, 30, 76, 199
  formation of ball lightning at bend, 91, 93
  persistence of, 199
  transverse waves, 31
Literature sources, 203
Loeb, L., 124, 128
Luminous phenomena
  air mass, 59, 175, 186
  ball of fire, 170, 182
  bubbles, 165
  clouds, 166, 186
  power, 59, 61, 189

Machine rheostatique, 159
Magnetic compression, 30
Magnetic field of ball lightning, 75, 116
Malan, D. J., 141
Manwaring, J. R., 186
Marcet, W., 175
Marchant, E. W., 184, 201
Mass density of ball lightning, 45
Mathias, B. T., 20, 63
Mathouillot, H., 131
McCrosky, R. E., 25, 97
Melted asphalt, 54
Merhaut, O., 92, 143
Metallic vapor, 176
Metastable molecules, 193
Methane, 174
Mills, A., 74
Modulated illumination, 80
Molecular energy exchange, 173
Molecular energy storage, 189, 199
Molecular excitation, 122, 145, 193, 195, 197
Molten metallic drops, 104, 177
Moncel, T. du, 148, 157, 159
Morris, W., 47
Motion of ball lightning, 36
Muller-Hillebrand, D., 76, 86
Multiple path, 86
Muschenbroeck philal, 158

Natural radiation, 201
Nauer, N., 164, 169
Neeson, F., 77, 176
Neugebauer, T., 63, 71
Newman, M., 152
Nielson, A., 57, 176
Nitrogen oxides, 52, 71, 163
Norinder, H., 94, 107, 131, 143
Nuclear reactions, 74

Odor of ball lightning, 37
Optical diameter of ball lightning, 48, 52, 77
Optical illusions, 136
Optical power, 61, 189
Orville, R. E., 192
Oscillating luminosity, 115
Oxygen excitation, 193, 199
Ozone ball, 63

Paneth, F. A., 8
Perceptual effects, 138
Periodicals, 203
Perlschnurblitz, 11
Persistence, 24, 189, 195
Petersen, H., 113, 143
Photographs
  of ball lightning, 79, 130, 139, 140
  of bead lightning, 12, 139
  known, but unavailable, 130
Piltschikoff, M., 162, 169
Pinch effect, 29, 30
Plante, G., 159, 164
Plasma form, 61, 64, 176, 184, 195
Plasmoid, 127, 184
Poey, M., 159
Polyester burn, 51
Ponnamperuma, C., 171
Poulter, R. M., 89, 114, 142, 143
Powell, J. R., 58, 67, 68, 69, 73, 77, 129, 186, 194, 197, 199
Prairie meteorite network, 25, 94

Pressure of ball lightning, 60
Probability of occurrence, 6, 97, 133
Prochnow, O., 17, 109, 131
Propane, 168, 170
Psychological effects, 136
Psychovisual effects, 138
Pulsating illumination, 80
Pyrotechnic appearance of ball lightning, 100, 143

Quantum mechanical model of ball lightning, 64, 71, 72

Raab, O., 131
Radiation from ball lightning, 51, 58, 70, 73
Radiofrequency discharge, 127, 146, 180, 197
Recombination, 124
References to ball lightning, 204
References to bead lightning, 31
Residue, 39, 101, 114, 196
Resonance conditions, 200
Retina retention, 134, 136
Return stroke, 2
Richmann, G. M., 38, 105, 148, 149
Riggenbach-Burckhardt, A., 12, 131
Righi, A., 122, 163
Ritchie, D. J., 64, 127, 184
Rodney, P. R., 25, 94
Roguet, A., 28
Roman candle firework display, 103
Room appearances of ball lightning, 37, 42, 43
Rossman, F., 131
Rutgers, G. A. W., 116

St. Elmo's Fire, 35, 37, 125, 134
Scheminzky, F., 18
Schmauss, A., 16
Schneidermann, K., 131
Scorched grass by ball lightning, 55
Scott, M., 101
Seigner, R., 13
Self-magnetic field, 29
Seliger, H. H., 73
Shagin, F., 87, 142
Shape of ball lightning, 35
Sharovoyi molnii, 33
Shorted generator producing ball lightning, 56, 58, 106, 146, 176, 177
Silberg, P. A., 56, 146, 177
Simultaneous photographs, 22, 24
Singer, S., 33, 103, 173
Singular trace of ball lightning, 110
Size of ball lightning, 35, 76, 138, 173, 200
Size change, 75, 168
Skepticism of ball lightning existence, 79, 117, 133, 139, 152, 161, 165
Smithsonian astrophysical observatory, 23
Snow particle charge, 40
Snowstorm observations of ball lightning, 40
Sodium vapor lamp, 12, 85, 90
Sokolov, M., 150
Sound of ball lightning, 37
Soviet research, 186
Spark, 123
Spectroscopy, 189
Spherical flame, 60, 173, 175
Spickerman, H., 86
Standing electromagnetic wave, 182, 200
Standler, R. B., 20, 84
Stationary image of ball lightning, 105
Stekolnikov, I. S., 76, 114, 131
Stenhoff, M., 51
Stepped leader, 2, 24, 97
Storm dependence of ball lightning, 39, 91
Streamers from ball lightning, 100, 124
Street lamps, 12, 84, 90
Stroke, 2
Structure of ball lightning, 36
Submarine fireball, 56, 146, 177
Subsun, 139
Summary, 139, 194
Surveys of ball lightning properties, 33

Teletov, G. S., 63
Temperature of ball lightning, 70, 73, 173, 193
Tensile strength of wood, 50
Terada, T., 41, 112
Tesla, N., 26, 59, 180
Thermal energy of ball lightning, 70, 72
Thermoblast of road, 54
Thermoluminescence, 74
Thompson, J. J., 180

Thornton, W. M., 63
Thunderstorm, 39, 41, 91
TNT, 63
Toepler, M., 17, 28, 116, 122, 134
Tomlison, C., 74
Tompkins, D. R., 25, 94, 144
Tornado observations of ball lightning, 41
Touchet, E., 28
Townsend, J., 123, 197
Transverse waves in lightning channel, 31
Triggered lightning discharge, 22, 148, 149, 175, 196
Trowbridge, J., 122, 163
Tuck, J. L., 134

Uman, M. A., 1, 29, 30, 76, 199
Unavailable photographs of ball lightning, 130
Uninterrupted trace of ball lightning, 110

Volcano observations of ball lightning, 40
Vonnegut, B., 41

Walter, B., 17, 109, 130
Water plume stroke, 20, 155
Watson, W., 152
Watson, W. K. R., 200
Wavelike structure of bead lightning, 16, 17
Weber, L., 159, 160, 161
Weisskopf, V., 133
Westphal, W., 116
Wind effects on ball lightning, 36, 41
Wittman, A., 54
Wolf, F., 18, 116, 131, 142
Wood piling damaged by ball lightning, 49
Wood, R. W., 127
Wooding, E. R., 50

Young, C. J., 87, 142
Young, G. A., 20, 155

Zimmerman, P. D., 49
Zoege von Manteuffel, P., 87, 142
Zschokke, W., 130